Rapid Prototyping, Tooling and Time Compression

by

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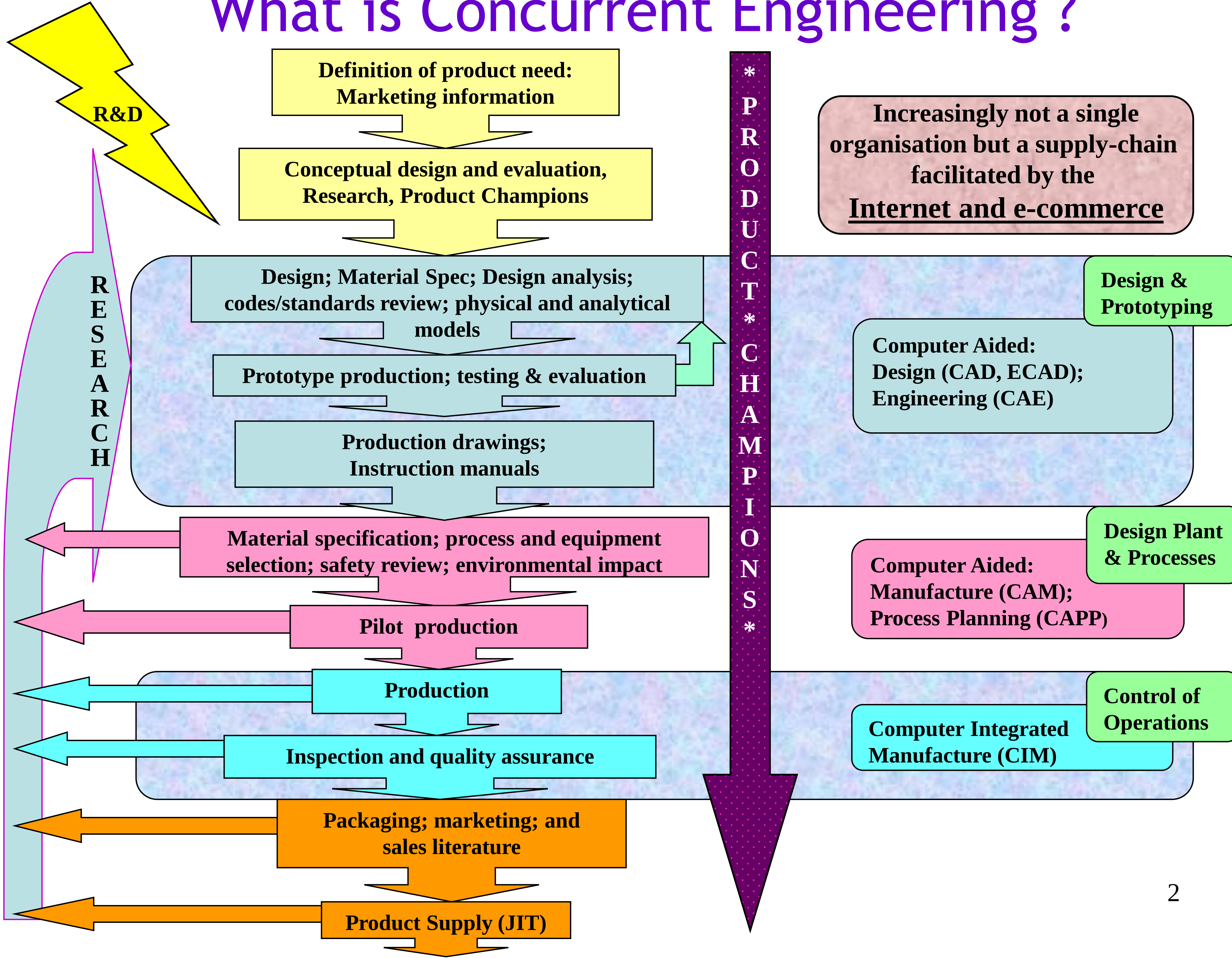
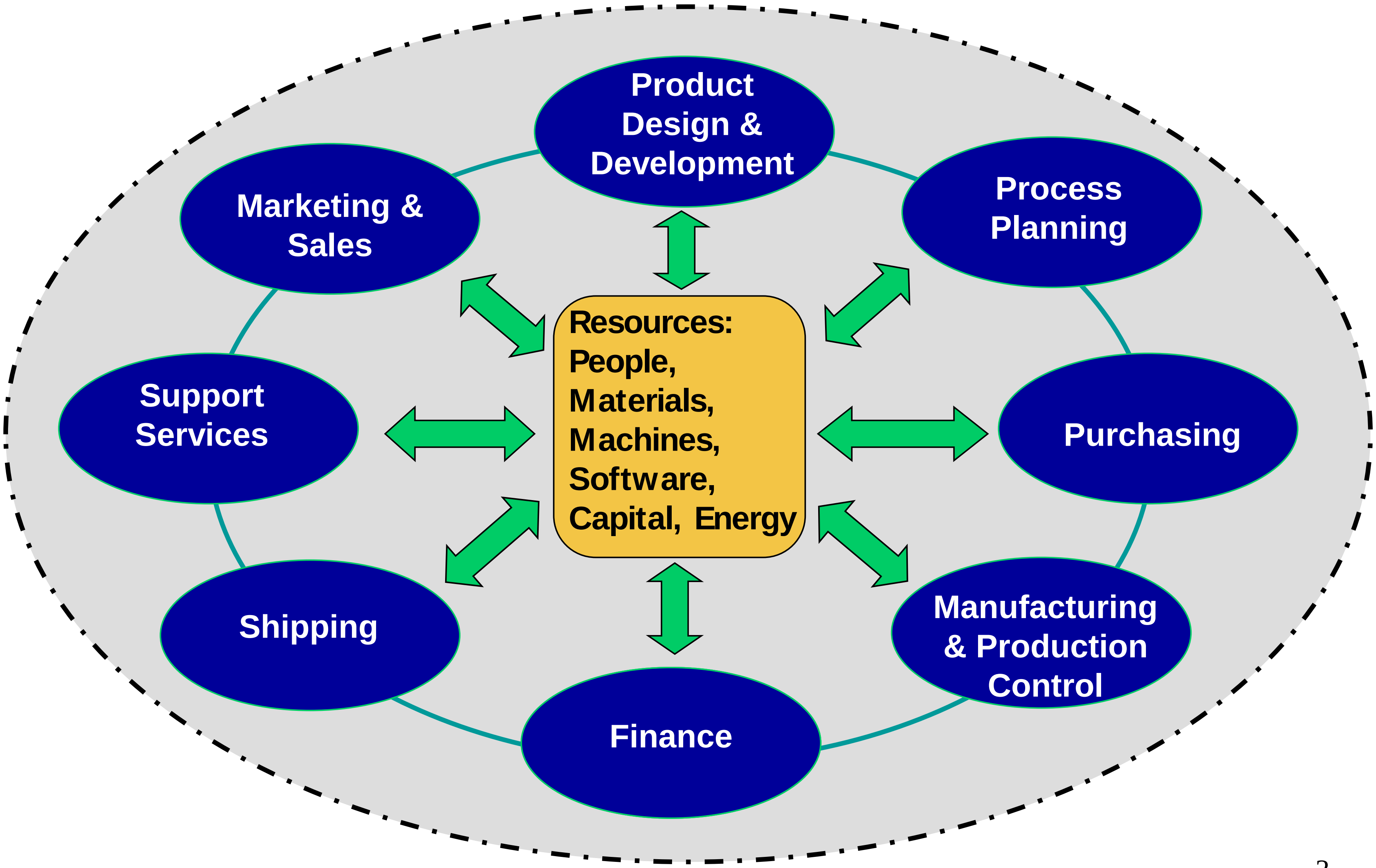
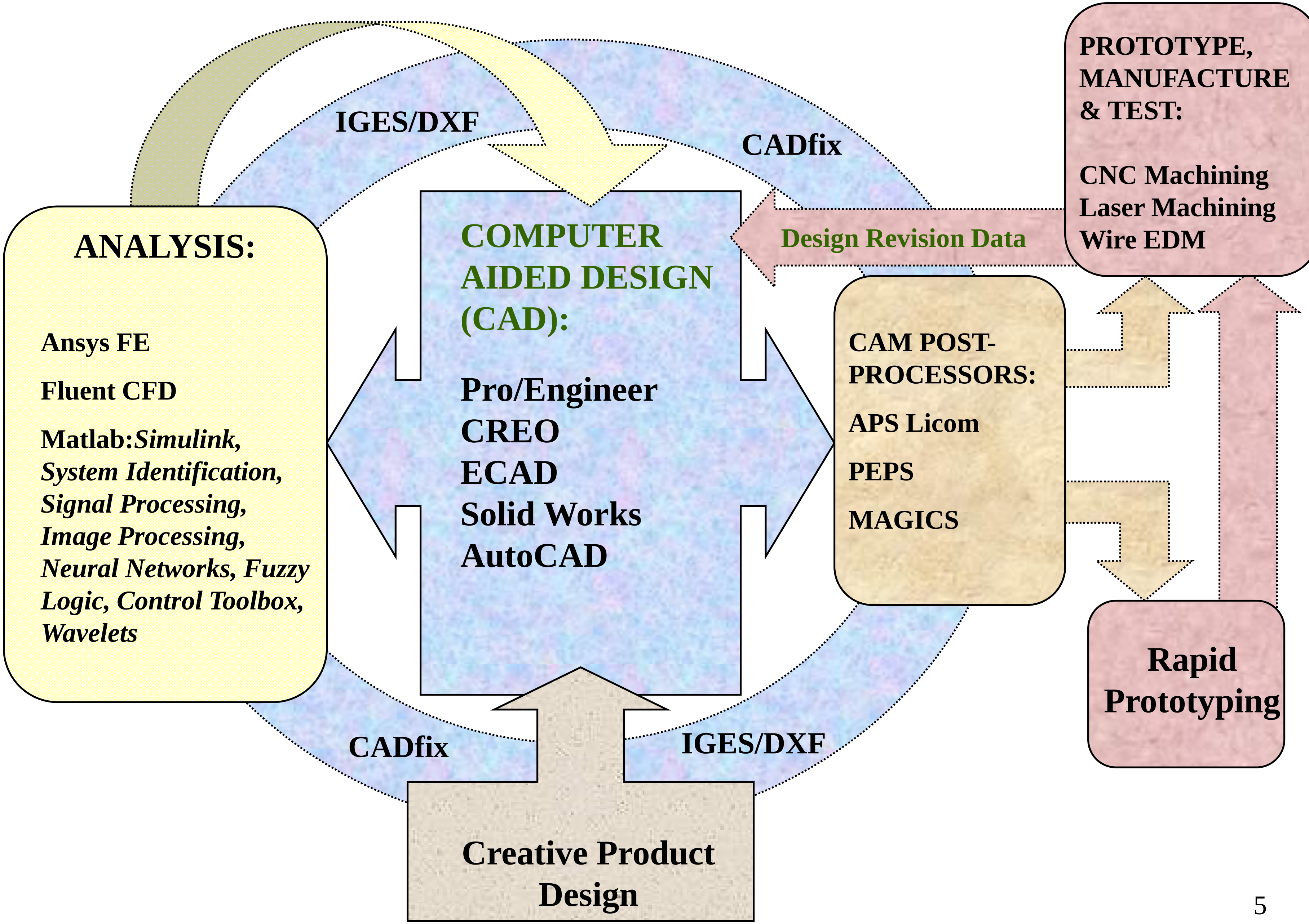
What is Concurrent Engineering ?



Computer Integrated Manufacturing System



CAD,CAE & CAM



ANALYSIS:
Ansys FE
Fluent CFD
Matlab:*Simulink, System Identification, Signal Processing, Image Processing, Neural Networks, Fuzzy Logic, Control Toolbox, Wavelets*
IGES/DXF
CADfix
COMPUTER AIDED DESIGN (CAD):
Pro/Engineer
CREO
ECAD
Solid Works
AutoCAD
Design Revision Data
PROTOTYPE, MANUFACTURE & TEST:
CNC Machining
Laser Machining
Wire EDM
CAM POST-PROCESSORS:
APS Licom
PEPS
MAGICS
Rapid Prototyping
CADfix
IGES/DXF
Creative Product Design

Figure 16a: **CFD optimisation of flow.**

Figure 16b: **CAD design of castings.**

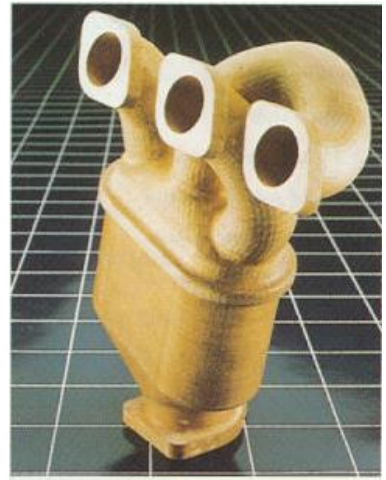
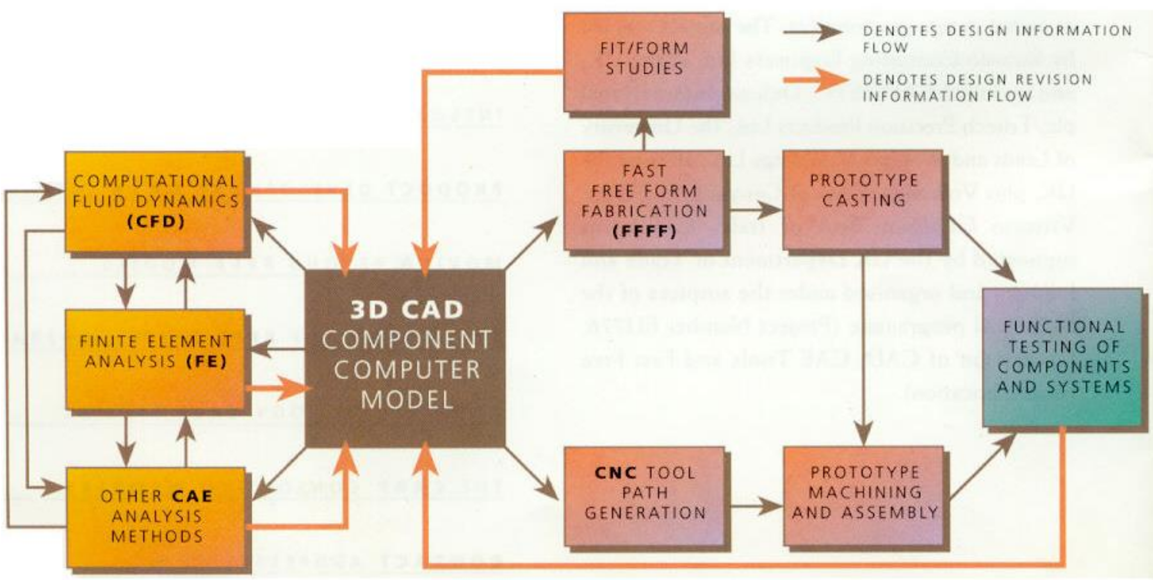


Figure 16c: **LOM models.**

Figure 16d: **Investment casting using LOM and SLS FFFF patterns.**

Courtesy of Ricardo CARP project



Technologies Enabling Product Innovation - Summary

- Rapid Prototyping - manufacture by layering processes:
  - Stereolithography
  - Selective Laser Sintering (SLS)
  - Direct Metal Laser Sintering (DMLS)
  - Laminated Object Manufacture (LOM)
  - Solid Ground Curing
  - 3D Printing

What are we trying to achieve ?

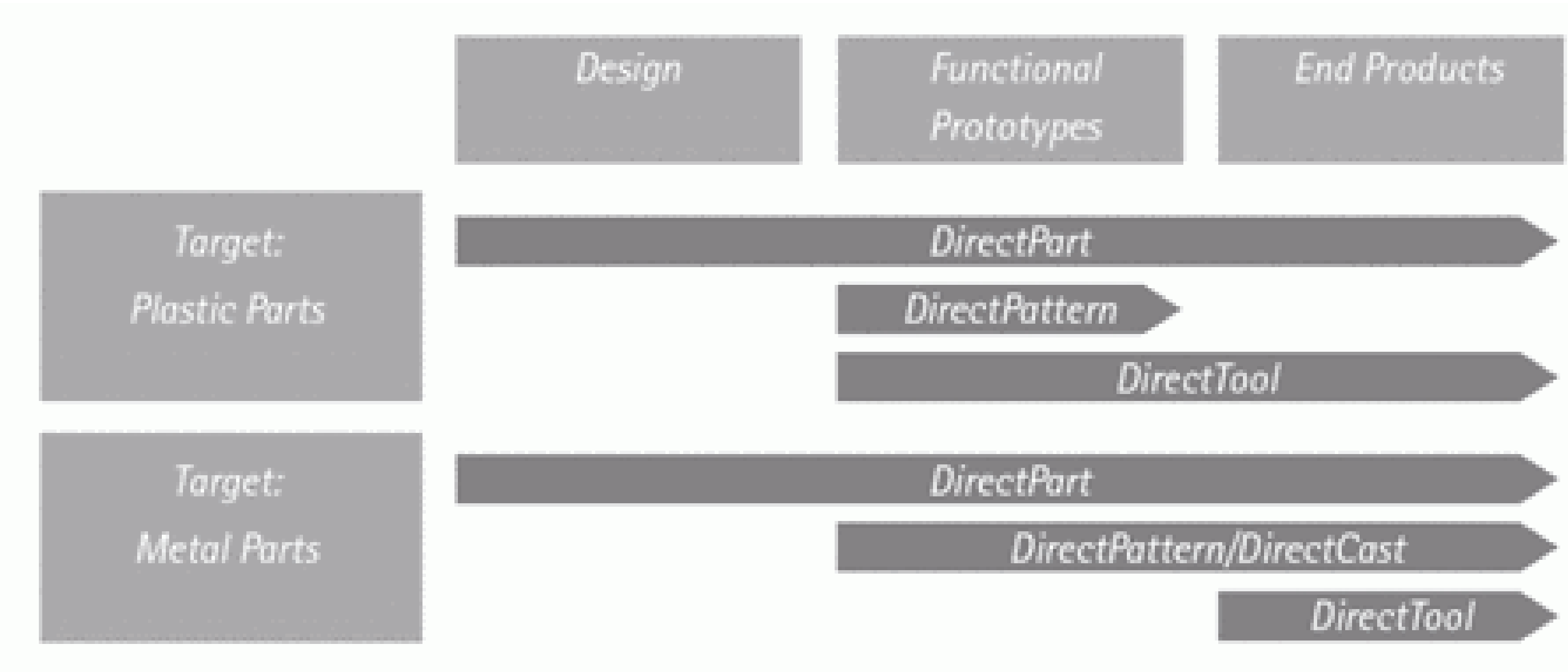


TABLE 20.1

Characteristics of Additive Rapid-prototyping Technologies

Process	Supply phase	Layer creation technique	Type of phase change	Materials
Stereolithography	Liquid	Liquid layer curing	Photopolymerization	Photopolymers (acrylates, epoxies, colorable resins, and filled resins)
Multi Jet/PolyJet modeling	Liquid	Liquid layer curing	Photopolymerization	Photopolymers
Fused-deposition modeling	Solid	Extrusion of melted polymer	Solidification by cooling	Polymers (such as ABS, polycarbonate, and polysulfone)
Ballistic-particle manufacturing	Liquid	Droplet deposition	Solidification by cooling	Polymers and wax
Three-dimensional printing	Powder	Binder-droplet deposition onto powder layer	No phase change	Ceramic, polymer, metal powder, and sand
Selective laser sintering	Powder	Layer of powder	Sintering or melting	Polymers, metals with binder, metals, ceramics and sand with binder
Electron-beam melting	Powder	Layer of powder	Melting	Titanium and titanium alloys, cobalt chrome
Laminated-object manufacturing	Solid	Deposition of sheet material	No phase change	Paper and polymers
Laser-engineered net shaping	Powder	Injection of powder stream	No phase change	Titanium, stainless steel, aluminum

TABLE 20.2

Mechanical Properties of Selected Materials for Rapid Prototyping

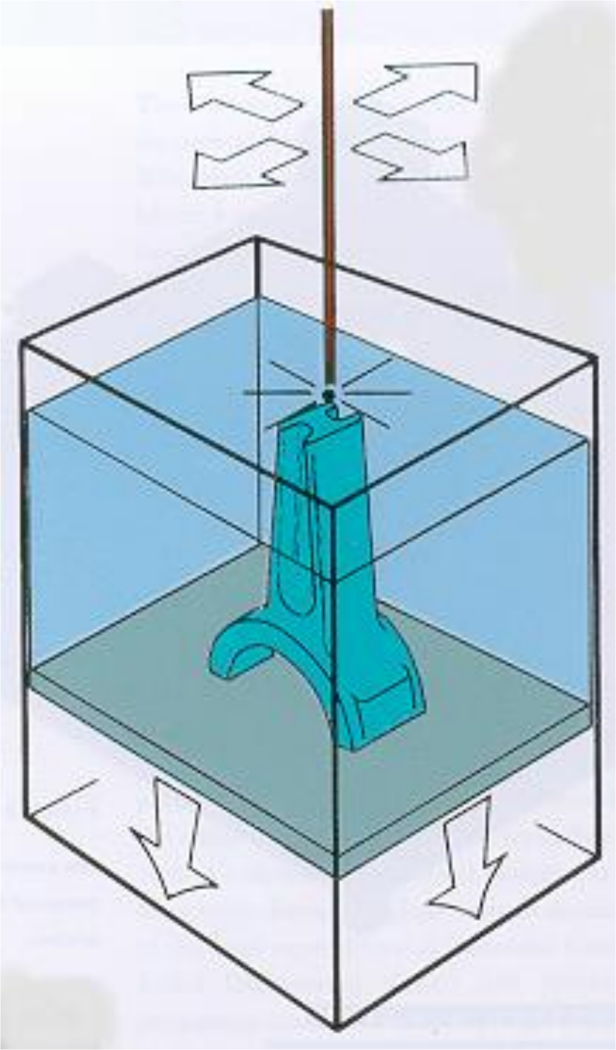
Process	Material	Tensile strength (MPa)	Elastic modulus (GPa)	Elongation in 50 mm (%)	Characteristics
Stereolithography	Accura 60	68	3.10	5	Transparent; good general-purpose material for rapid prototyping
	Somos 9920	9	1.35–1.81	15–26	Transparent amber; good chemical resistance; good fatigue properties; used for producing patterns in rubber molding
	WaterClear Ultra	56	2.9	6–9	Optically clear resin with ABS-like properties
	WaterShed 11122	47.1–53.6	2.65–2.88	11–20	Optically clear with a slight green tinge; mechanical properties similar to those of ABS; used for rapid tooling
	DMX-SL 100	32	2.2–2.6	12–28	Opaque beige; good general-purpose material for rapid prototyping
PolyJet	FC720	60.3	2.87	20	Transparent amber; good impact strength, good paint adsorption and machinability
	FC830	49.8	2.49	20	White, blue, or black; good humidity resistance; suitable for general-purpose applications
	FC 930	1.4	0.185	218	Semiopaque, gray, or black; highly flexible material used for prototyping of soft polymers or rubber

TABLE 20.2

Mechanical Properties of Selected Materials for Rapid Prototyping

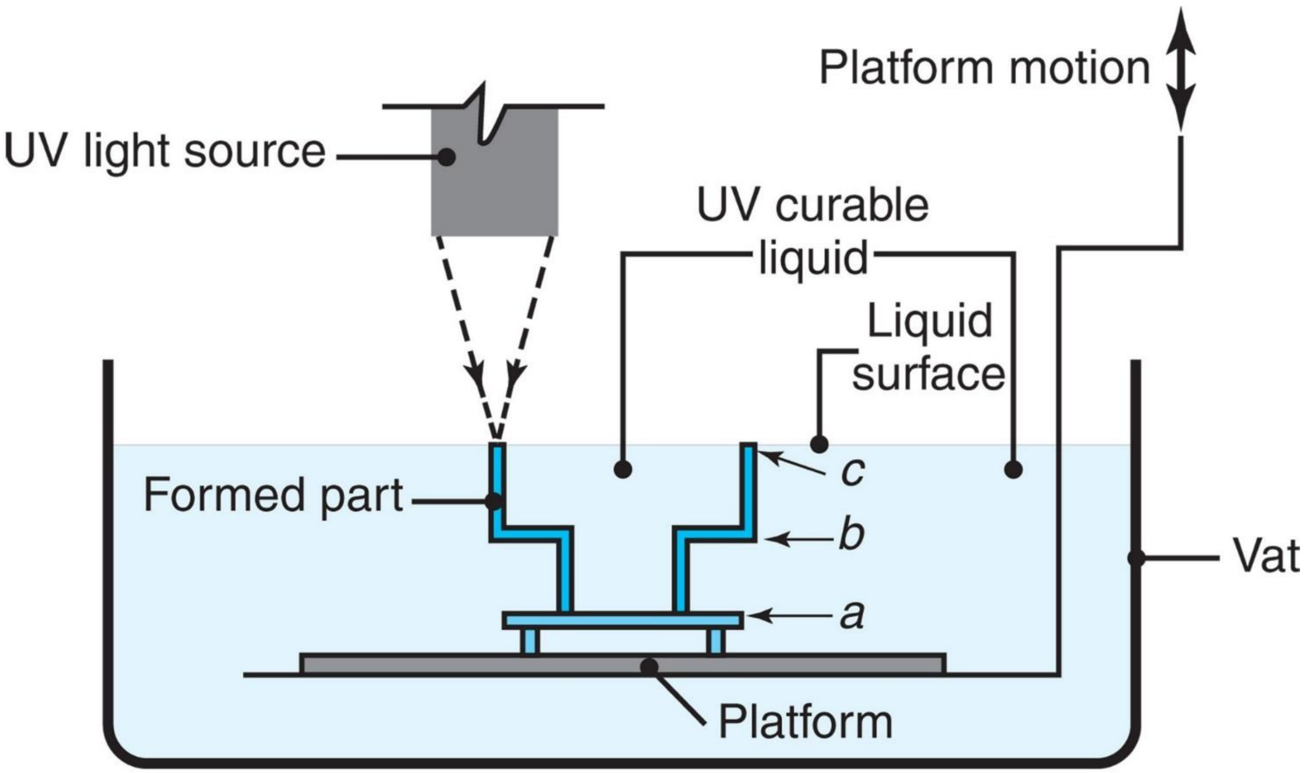
Process	Material	Tensile strength (MPa)	Elastic modulus (GPa)	Elongation in 50 mm (%)	Characteristics
Fused-deposition modeling	Polycarbonate	52	2.0	3	White; high-strength polymer suitable for rapid prototyping and general use
	Ultem 9085	71.64	2.2	5.9	Opaque tan, high-strength FDM material, good flame, smoke and toxicity rating
	ABS-M30i	36	2.4	4	Available in multiple colors, most commonly white; a strong and durable material suitable for general use; biocompatible
	PC	68	2.28	4.8	White; good combination of mechanical properties and heat resistance
Selective laser sintering	WindForm XT	77.85	7.32	2.6	Opaque black polymide and carbon; produces durable heat- and chemical-resistant parts; high wear resistance
	Polyamide PA 3200GF	45	3.3	6	White; glass-filled polyamide has increased stiffness and is suitable for higher temperature applications
	SOMOS 201	—	0.015	110	Multiple colors available; mimics mechanical properties of rubber
	ST-100c	305	137	10	Bronze-infiltrated steel powder
Electron-beam melting	Ti-6Al-4V	970–1030	120	12–16	Can be heat treated by HIP to obtain up to 600-MPa fatigue strength

Scanning Beam Stereolithography



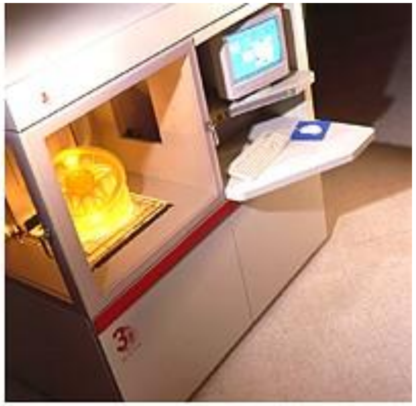
3D Systems SLA 3500 Series

Schematic illustration of the stereolithography process.



https://www.youtube.com/watch?v=_9m5gEtow88 SLA

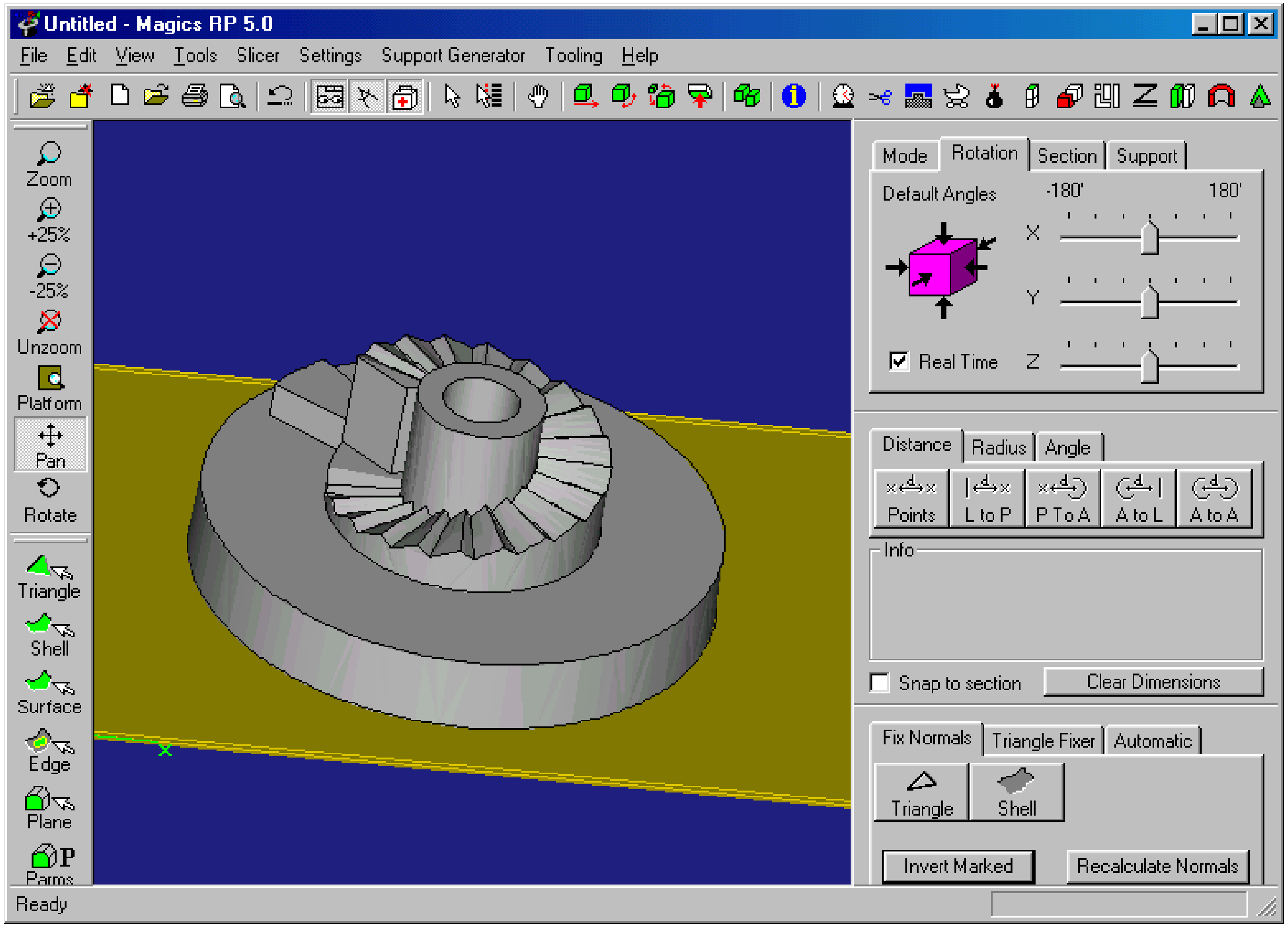
3D Systems Scanning Beam Stereolithography System



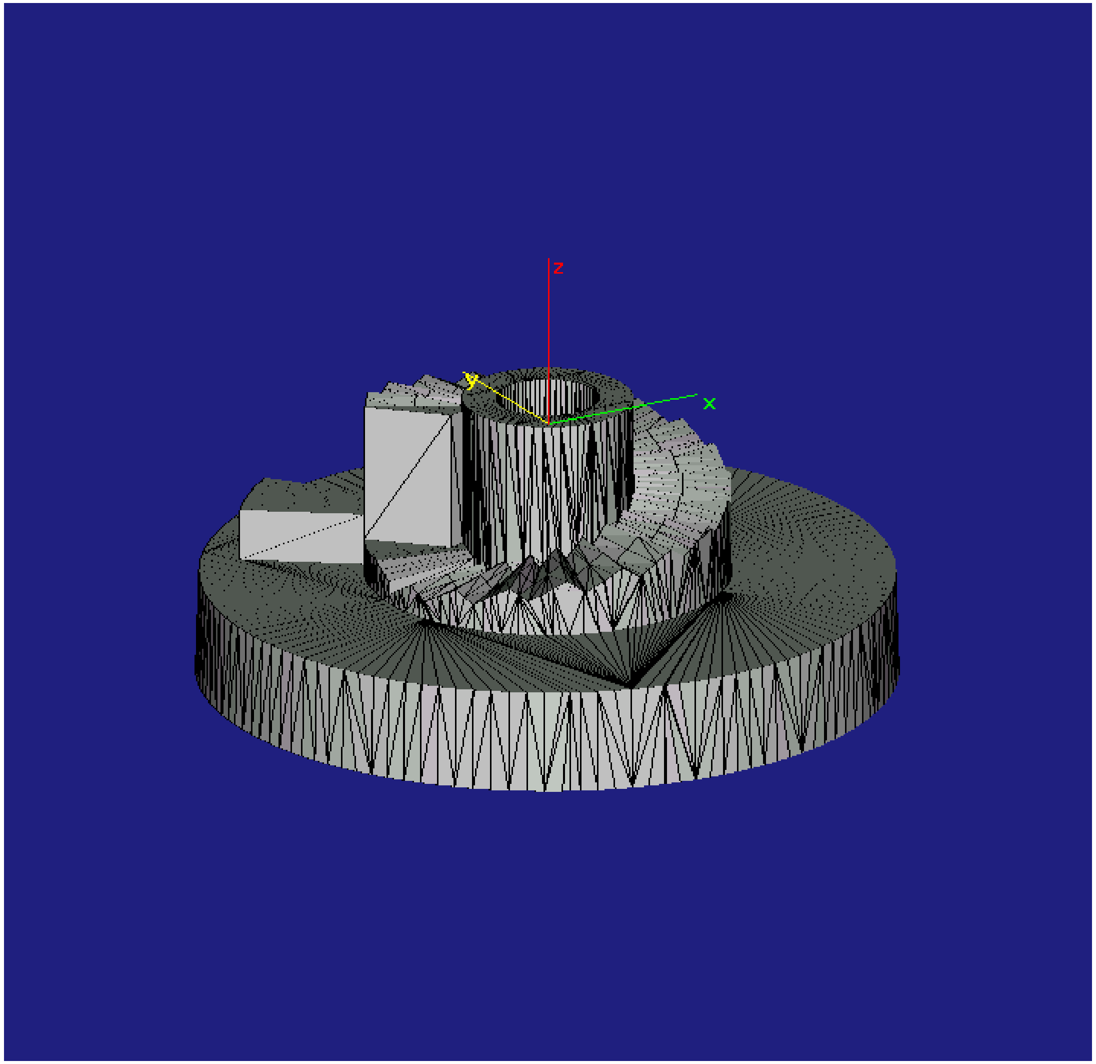
SLA 7000 Series - Dual spot laser technology gives greater speed

iPro 8000 SLA Printer – 650x750x550mm

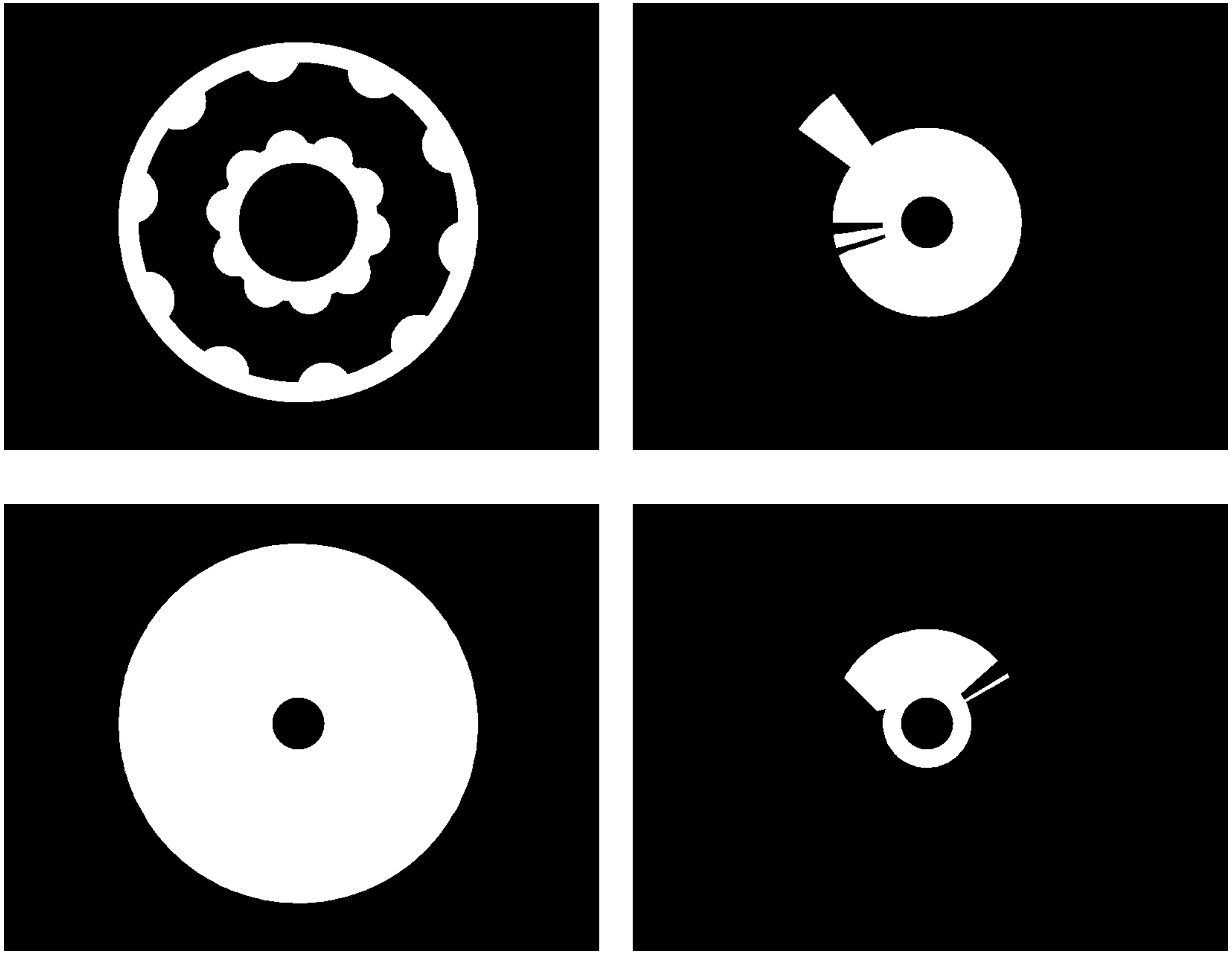
STL Interface



STL triangle format

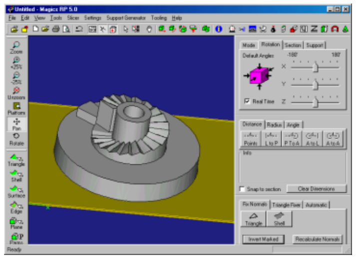


Slices from STL Model

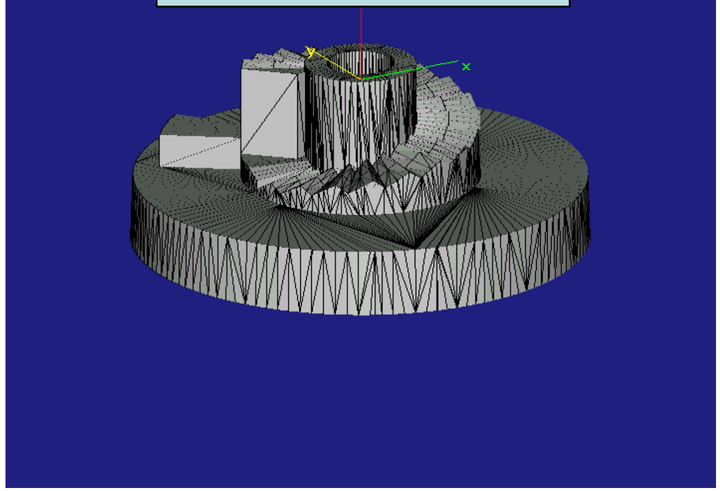


Data Flow

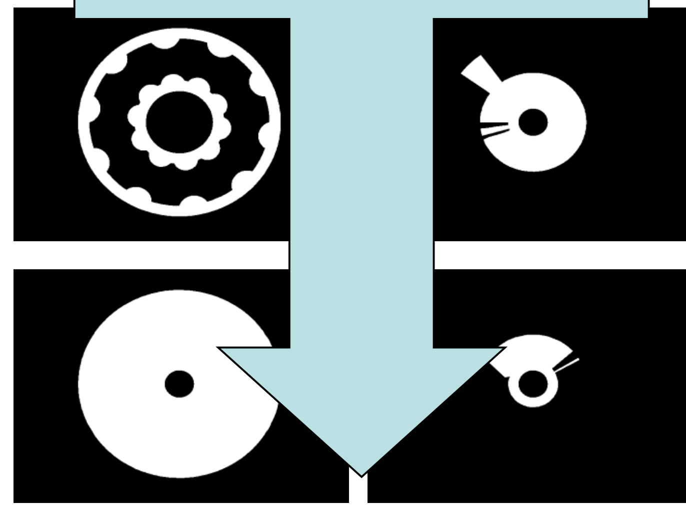
Generate 3D CAD model of object



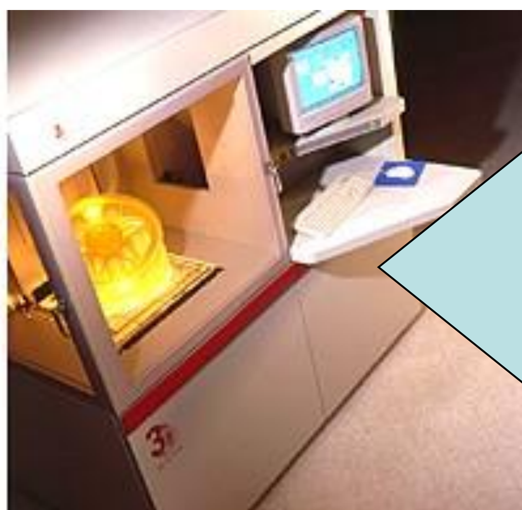
Generate STL file on CAD system



Generate support structures, if required, and object level slice data on target machine

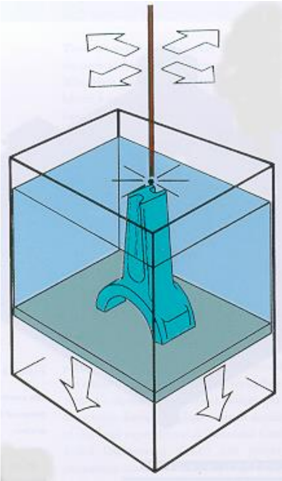


Generate vector scanning data to control the beam scanning mirrors or inkjet head, the Z axis and machine process control instructions



Rapid Prototyping

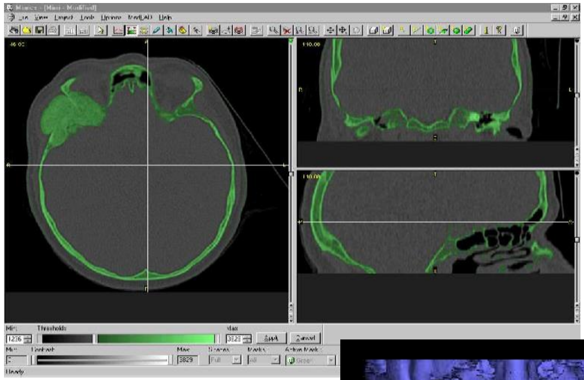
Stereolithography



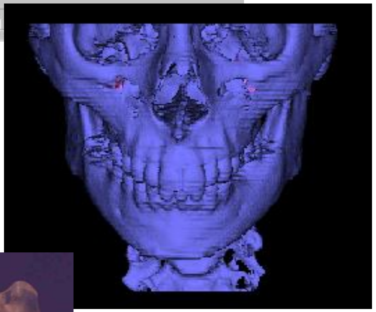
Courtesy of Ricardo

SLA 250

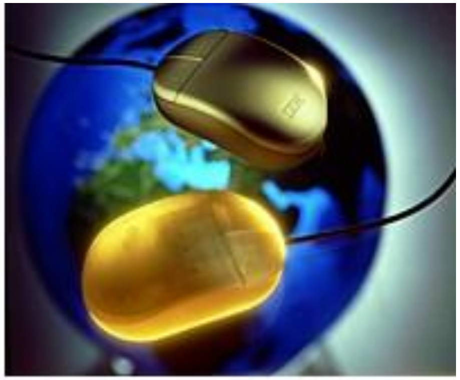
Magnetic Resonance Imaging



3D Model



Daewoo manifold



Logitech - From quote to working prototype in 7 days - 3D Systems

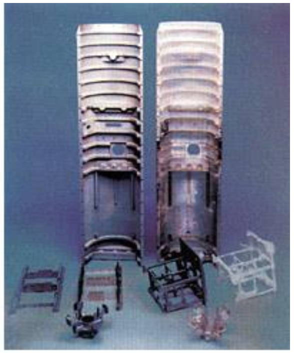
SLA Model

SLA250 Stereolithography

Products Using 3D Systems SLA Machine

16 weeks to 39hrs; £22,000 to £1200

Rover - Injection manifold for new engine - 90% lead time reduction



Texas Instruments -
New shell casing – 20 off
$450,000 saving on tooling

Oldsmobile Aurora – 500 ABS parts
9 weeks to 4 weeks - TC 50% Bose Corp

Johnson Controls for Coca-Cola - 11 hours build time, 1 week design

Electrolux - Vacuum Cleaner
50% lead time reduction

Black & Decker - Shrub Trimmer
100 days 30 functioning prototypes

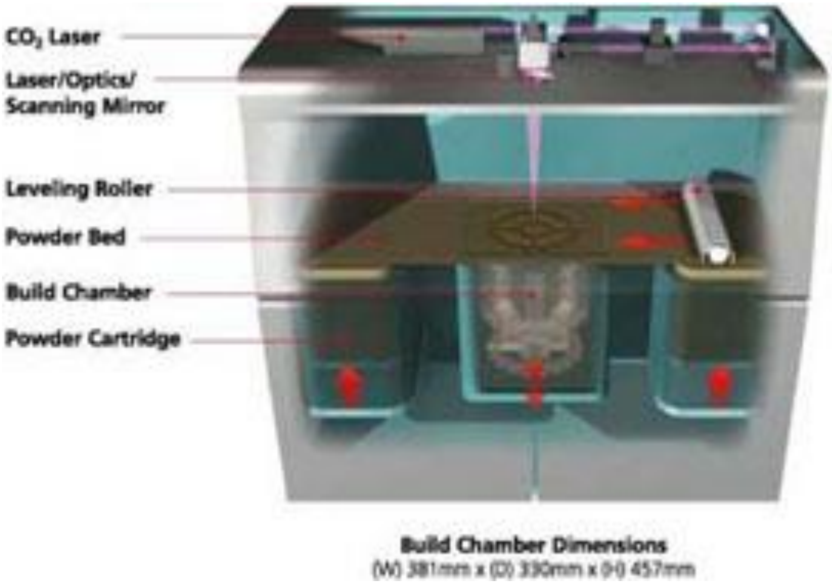
https://www.youtube.com/watch?v=4y-m1URlh00

Coffeemaker prototypes produced through MultiJet modeling and final product (at right).

Source: Courtesy Alessi Corporation, and 3D Systems, Inc.

https://www.youtube.com/watch?v=apm5Gn2s_-M

SLS system



1. Spread a layer of powdered material. As the process begins, a precision roller mechanism automatically spreads a thin layer of powdered SLS material across the build platform.

2. Sinter a cross-section of the CAD file. Using data from the STL file, a CO_2 laser selectively draws a cross section of the object on the layer of powder. As the laser draws the cross section, it selectively "sinters" (heats and fuses) the powder creating a solid mass that represents one cross section of the part.

Sinterstation 2500*plus*

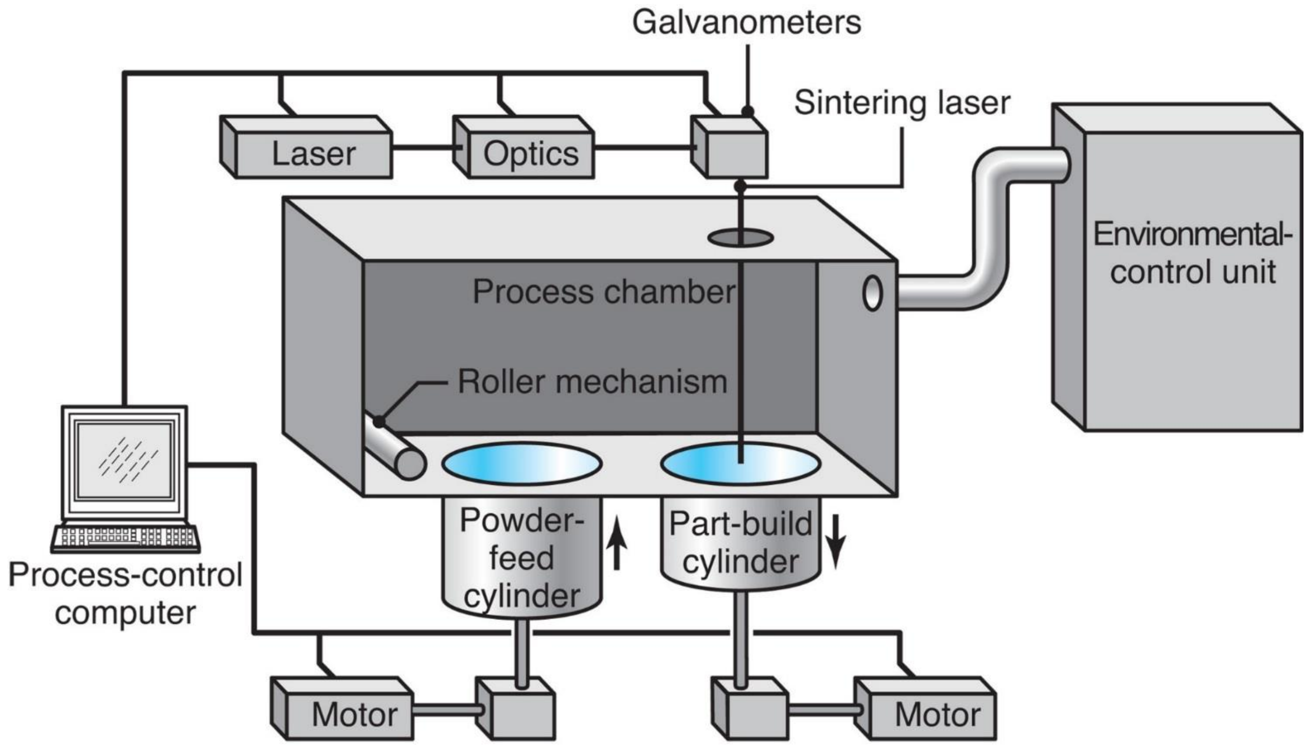
1) More material choices: plastic, elastomer, metal, or ceramic

2) More application options: functional prototypes, tooling, patterns—even final parts.

3) Build chamber dimensions (W) 381 mm x (D) 330 mm x (H) 457 mm

Schematic illustration of the selective-laser-sintering process.

Source: After C. Deckard and P.F. McClure.



https://www.youtube.com/watch?v=9E5MfBAV_tA **SLS**

SLS - Materials

Functional Plastic Prototypes - Create visual models, functional prototypes, durable patterns—even plastic parts for final use. *DuraForm Polyamide and DuraForm Glass Filled*

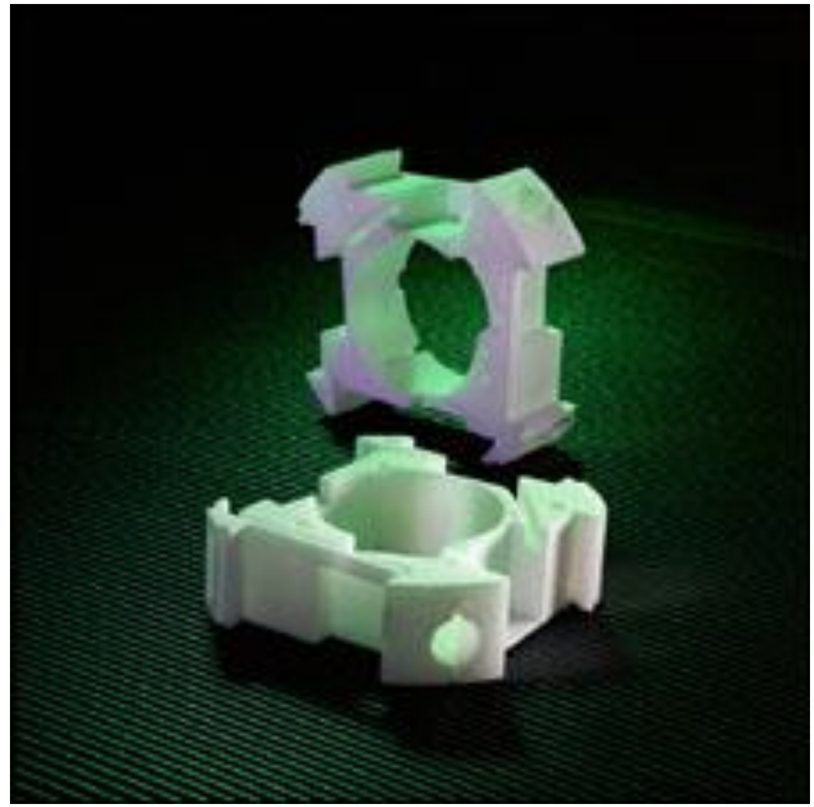
Durable Elastomer Prototypes- Produce, flexible, rubber-like prototypes and parts. *SOMOS 201*

Casting Patterns, Cores, and Molds - Quickly generate investment casting patterns or sand casting cores and molds. *CastForm Polystyrene, SandForm Zr, SandForm Si*

SLS Material: DuraForm PA™ - Plastic

Summary:
NASA used its in-house Sinterstation® system and DuraForm PA™ to quickly produce a **"science cup,"** a tray-like fixture that holds a variety of instruments, wiring, and batteries within a hockey puck-sized, self-contained spacecraft called the Free Flying Magnetometer (FFM).

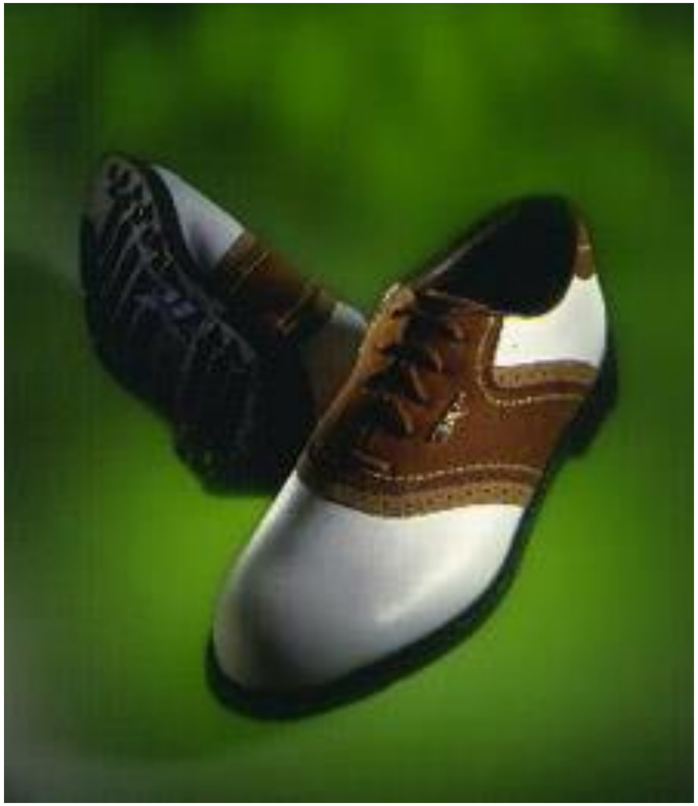
The parts generated on the Sinterstation cost only **300 US $ to produce**, compared to the **3,000 to 5,000 US $** it would have taken to fabricate the parts using traditional machining methods in aluminium, steel, or titanium



SLS Material SOMOS 201 - Elastomer

Summary
Reebok's Golf Division was in the early stages of developing a new spikeless golf shoe sole design and needed a fast, cost-effective way to create a flexible, testable prototype. Using traditional prototyping methods (standard tooling and injection moulding) would have taken **30 to 60 days and cost Reebok $3,500 to $4,000 per prototype**.

Reebok took another approach and prototyped the new sole design on its in-house Sinterstation system using SOMOS® 201. The process took just **seven hours and about $250 worth of SOMOS 201**. The prototype soles were affixed to a pair of golf shoes and worn by an experienced golfer for two rounds of golf.



Duraform Flex Plastic

Above: Radiator hose prototype withstands bending without permanent damage or deformation (shown without infiltrant).

SLS Material - Sandform

Summary:
When Woodward Governor Company (WGC) needed a casting of a new aircraft fuel control system for a gas turbine engine, it faced a formidable challenge: finding a process that could produce a large, complex casting within a very tight time frame.

Conventional tooling would have typically required **35 weeks**, just to generate the tools. Then it would have taken **another 12 weeks** to get the first casting.

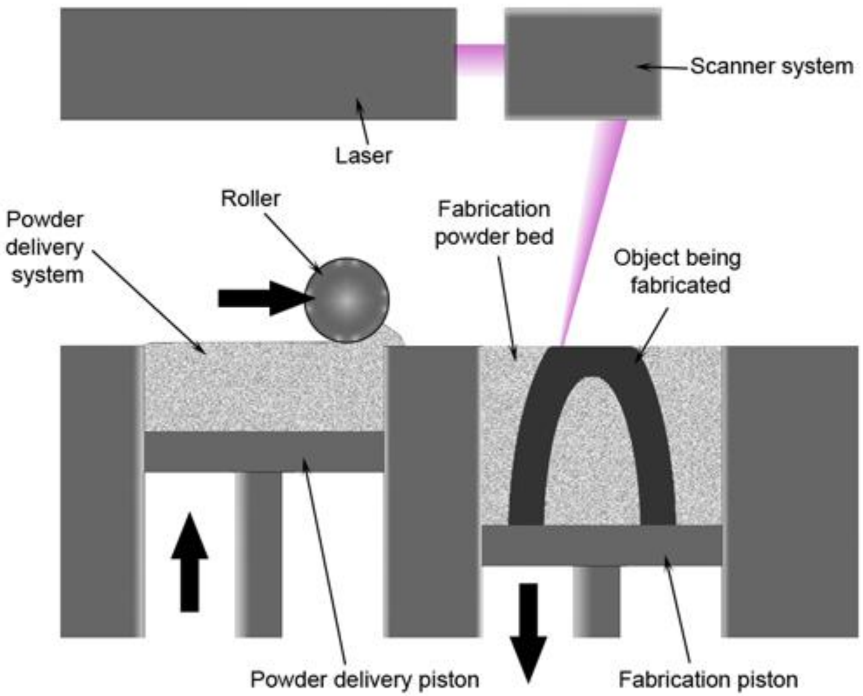
These times were **cut in half**. It took just two months to get the sand cores. What's more, the cost was only **20% of the cost** of conventional tooling.

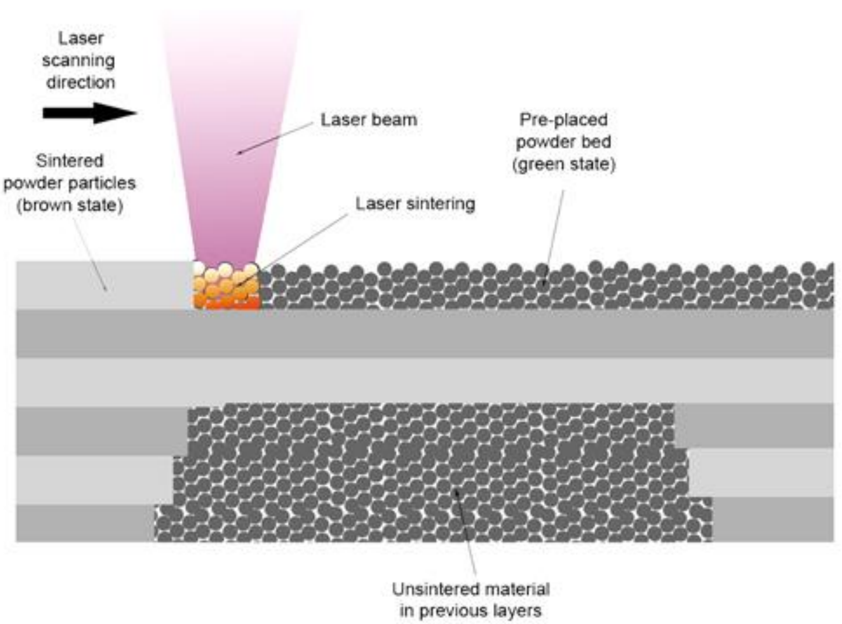
Direct Metal Laser-Sintering (DMLS)

EOSINT M 280 builds metal parts using Direct Metal Laser-Sintering (DMLS)

Sintering

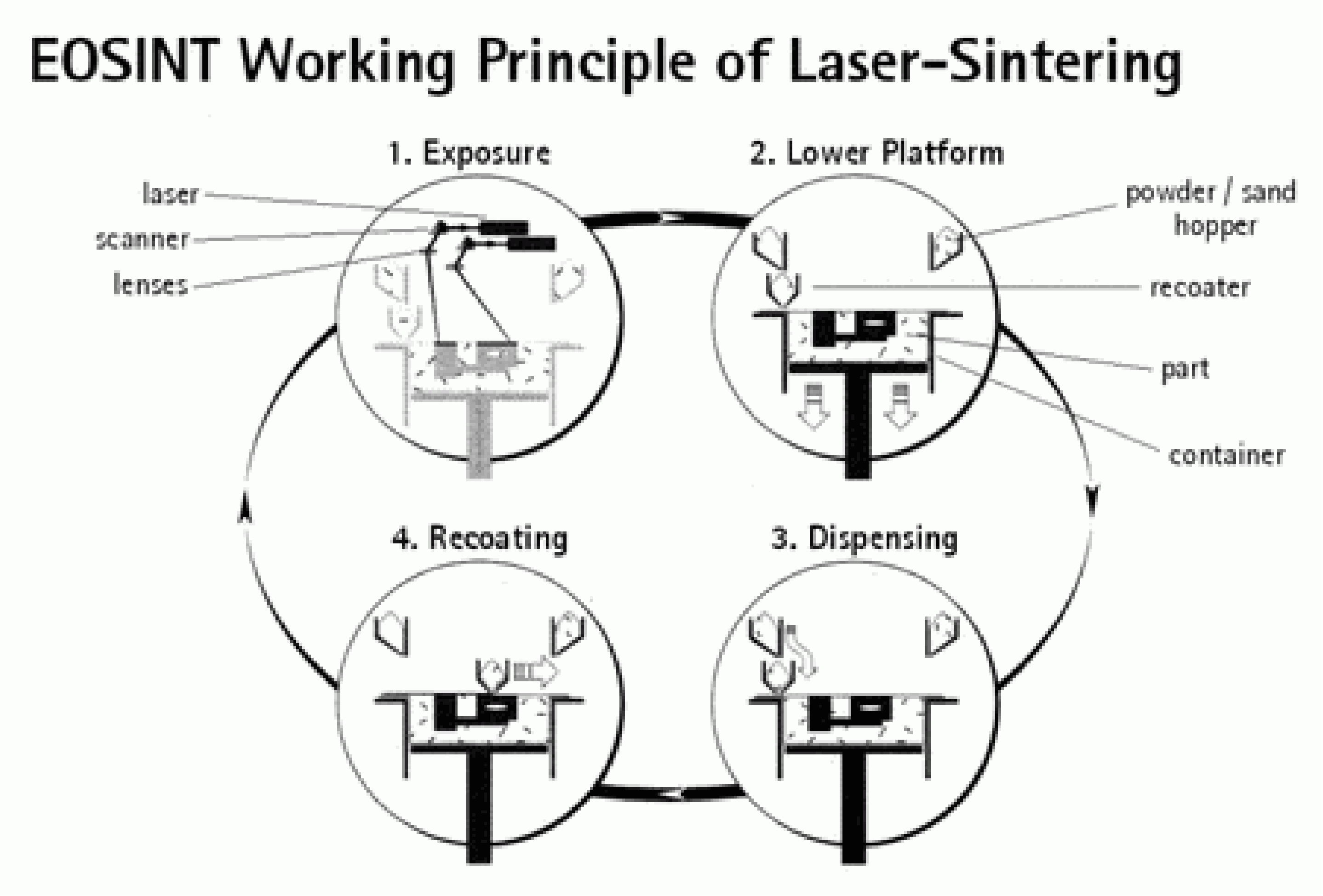
http://www.youtube.com/watch?v=VImKhUD-8hk





DMLS Direct Metal Laser Sintering process in action utilizing EOS GmbH platform, the M280. This technology sinters layers of fine metal alloys utilizing a 100 watt laser to additively manufacture real, fully dense metal parts.

How does it work ?



What can you do with the EOSINT M 280 ?

Sintered tool insert

Completed injection mould

Project took 6 days from start to finish

Two small LED polycarbonate light guide moulded parts EGi PAKTO

Injection Mould (core side) for two components

Four completed injection moulding tools

5000 sets (14 parts per set) moulded in six weeks, best quote 16 weeks

Production of a joystick for a construction vehicle. Moulded components & assembled joystick FIT GmbH

How Does it Perform ?

- Laser Type: Yb-fibre laser, 200 W or 400W
- Layer Thickness:20 - 60 µm
- Effective building volume (including building platform):250mm x 250mm x 325mm
- Building speed (material-dependent): 2 - 20 mm^3/s
- Scan speed: up to 7.0 m/s
- Variable focus diameter:100 - 500 µm

What Materials are available for EOSINT M 280 systems ?

- **DirectMetal 20**
  - Bronze-based mixture Injection moulding tooling, functional prototypes
- **EOS MaragingSteel MS1**
  - 18 Mar 300 / 1.2709 Injection Moulding series tooling, engineering parts
- **EOS StainlessSteel GP1**
  - Stainless steel 17-4 / 1.4542 Functional prototypes and series parts, engineering and medical

What Materials are available for EOSINT M 280 systems ?

- **EOS StainlessSteel PH1**
  - Hardenable Stainless steel Functional prototypes and series parts, engineering and medical
- **EOS CobaltChrome MP1**
  - CoCrMo superalloy Prototypes and series parts, engineering, medical, dental
- **EOS CobaltChrome SP1**
  - CoCrMo superalloy Dental restorations (series production)

What Materials are available for EOSINT M 280 systems ?

- **EOS Titanium Ti64**
  - Ti6Al4V light alloy Prototypes and series parts, aerospace, motor sport etc.
- **EOS Titanium TiCP**
  - Pure titanium Functional prototypes and series parts, medical dental
- **EOS Aluminium AlSi10Mg**
  - **-** Light Metal for Motorsports and Aerospace Interior Applications

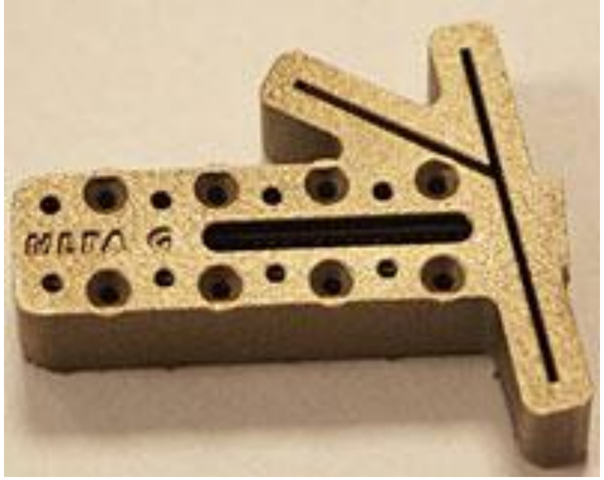
What Materials are available for EOSINT M 280 systems ?

- **EOS Aluminium AlSi10Mg/200 °C**
  - Light Metal for Motorsports and Aerospace Interior Applications
- **EOS NickelAlloy IN625**
  - Nickel-Chromium Alloy for Aerospace, Motorsports and Industry
- **EOS NickelAlloy HX**
  - Nickel-Alloy for Aerospace and Industry

Medical Applications

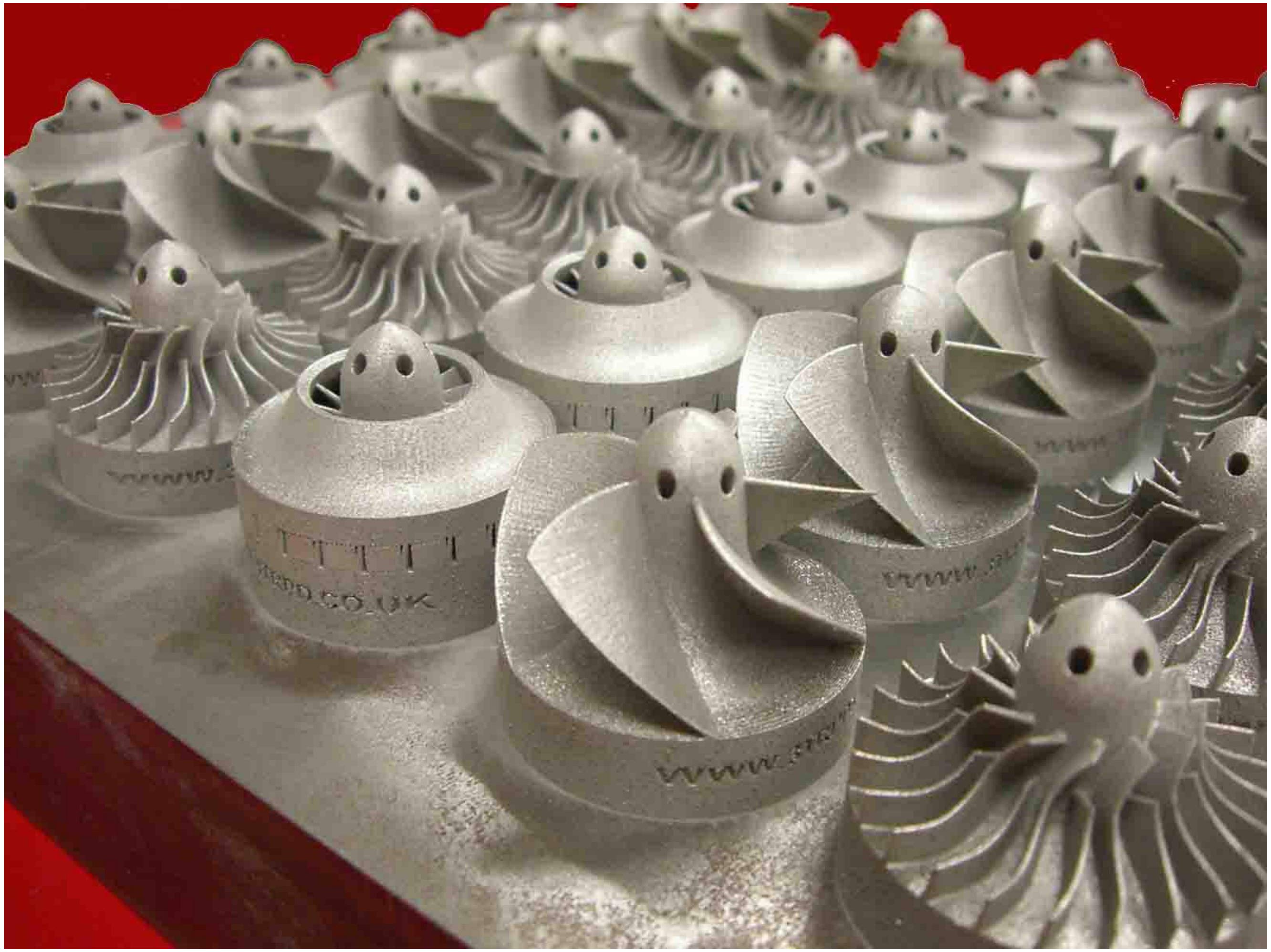
Knee implant in EOS CobaltChrome MP1
(Source: EOS)

Medical devices in EOS StainlessSteel 17-4
(Source: PEP / DePuy)



Components for a sawing guide for big toe joint in DirectMetal 20 (Built on an EOS M250Xtended)
(Source: PEP/DePuy)

Bed of Aerospace parts built using DMLS

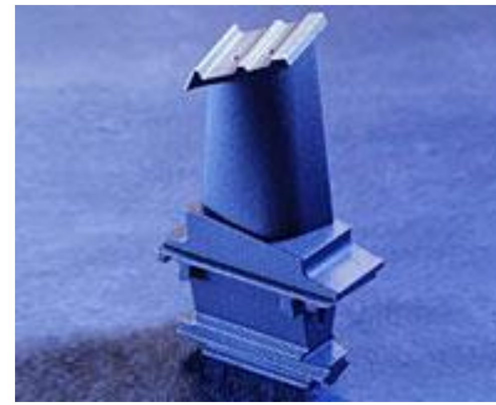


Formula 1 & Aerospace

http://www.youtube.com/watch?v=1CizD2YLTGg&feature=related

Engine exhausts in Cobalt Chrome (EOS CC MP1)

Propeller prototype for wind tunnel testing in Bronze (DirectMetal EOS DM20)



Turbine blade in Cobalt Chrome (EOS CC MP1)

Examples of Aerospace Parts built on 3T's EOS M270 machines in Cobalt Chrome

CobaltChrome MP1 superalloy for fully-functional aircraft engine parts

e-Manufacturing Solutions

Aerospace

Straightener for an helicopter gas-turbine engine. PEP/Turbomeca/Best in Class

Prototypes for Test Rigs

Requirements

- Functional prototypes for developing helicopter gas-turbine engine components
- Capable of running in test-bed conditions, e.g. high strength at high temperature

Solution

- Production with EOSINT M system using EOS CobaltChrome MP1 superalloy

Result

- Can be delivered in less than a week
- Can be automatically polished
- Properties fulfill requirements for running on test-rig

Source: PEP/Turbomeca/Best in Class

EOS IN718 combuster part for high temperature environment

e-Manufacturing Solutions

Aerospace

Thin walled turbine combustion chamber, produced on EOSINT M system, material EOS Nickel Alloy IN 718

Demonstration part

EOSINT M enables product optimization

- For aerospace devices
- New design concepts

Aerospace part design

- High complexity
- Thin walled
- Large size (max Ø 248mm ~10 inches)

New materials

- EOS Nickel Alloy IN718
- EOS Nickel Alloy IN 625
- Hastalloy X

Materials Solutions
Rapid development to meet environmental challenges

Source: Materials Solutions

Function integration for fuel systems

Aerospace

Fuel Injector & Swirler

Challenge
- Improve fuel efficiency of jet engines
- Optimize airflow and fuel swirling
- Cooling with integrated fuel channels

Solution
- Laser sintered on EOS M system
- Material: EOS CobaltChrome MP1

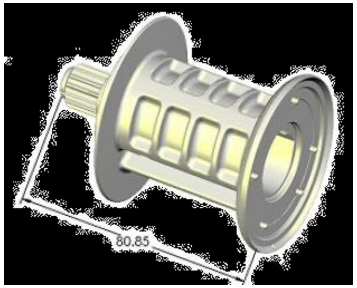
Benefits
- Highly complex design built as "one piece"
- Cost - < 50%
- Weight reduction - < 40%
- Increased robustness – no joining sections

Source: EOS GmbH, Morris Technologies

Tooling Inserts

Die casting tool (Maraging Steel)

Prototype tooling, Bronze DM20
Low volume Injection Moulding

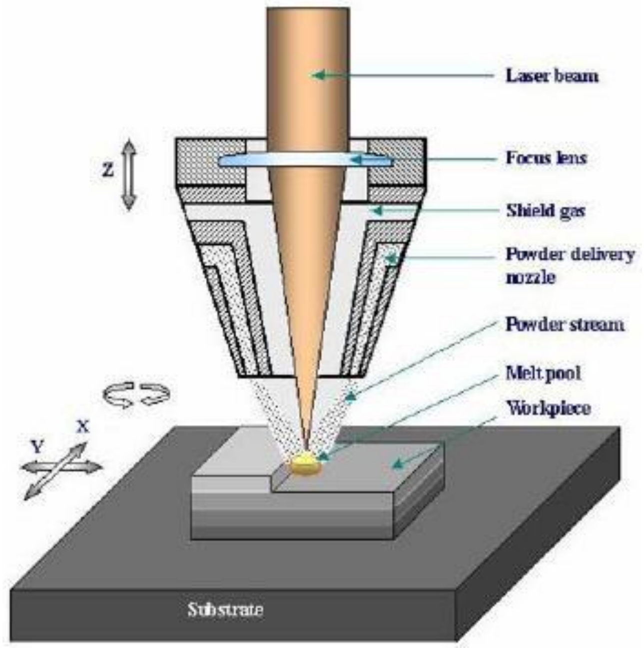


Die cast car safety belt winder,
1,500 aluminium parts produced in
good quality more possible
with coating

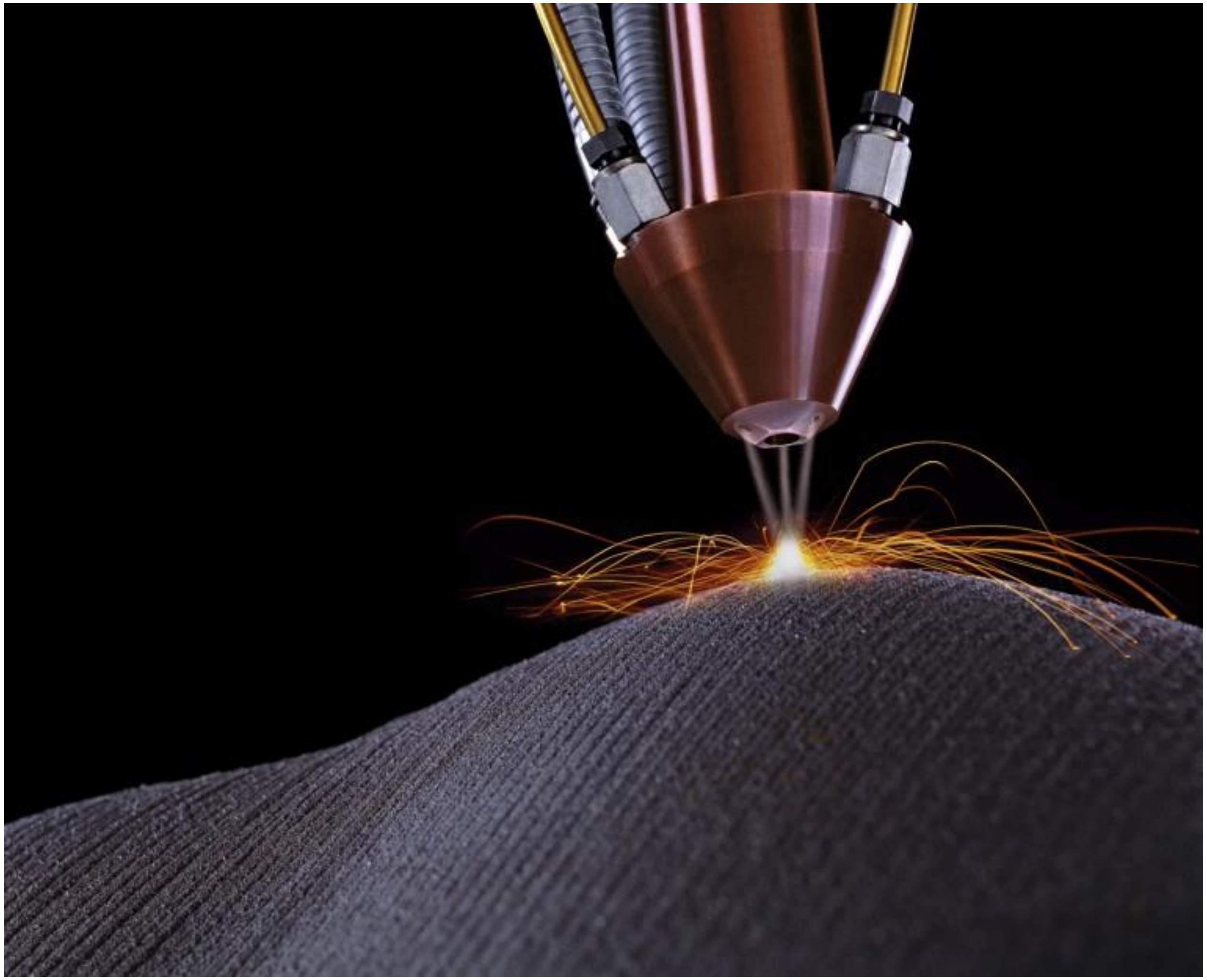
http://www.youtube.com/watch?v=88BPmL8cGAo&feature=related

Laser Deposition Technology (LDT)

https://www.youtube.com/watch?v=d2foaRi4nxM

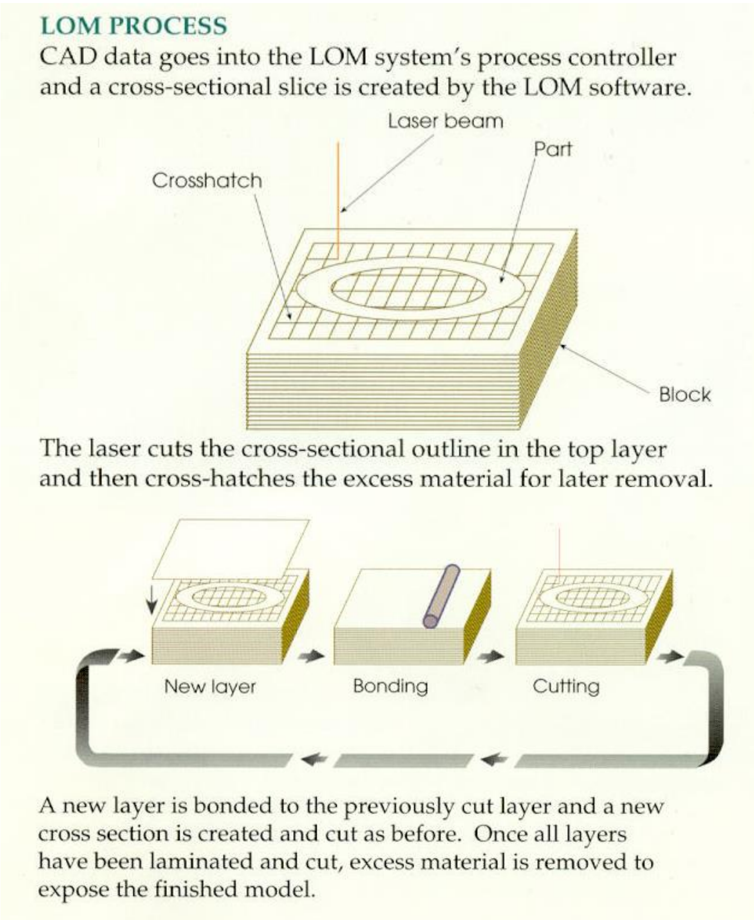


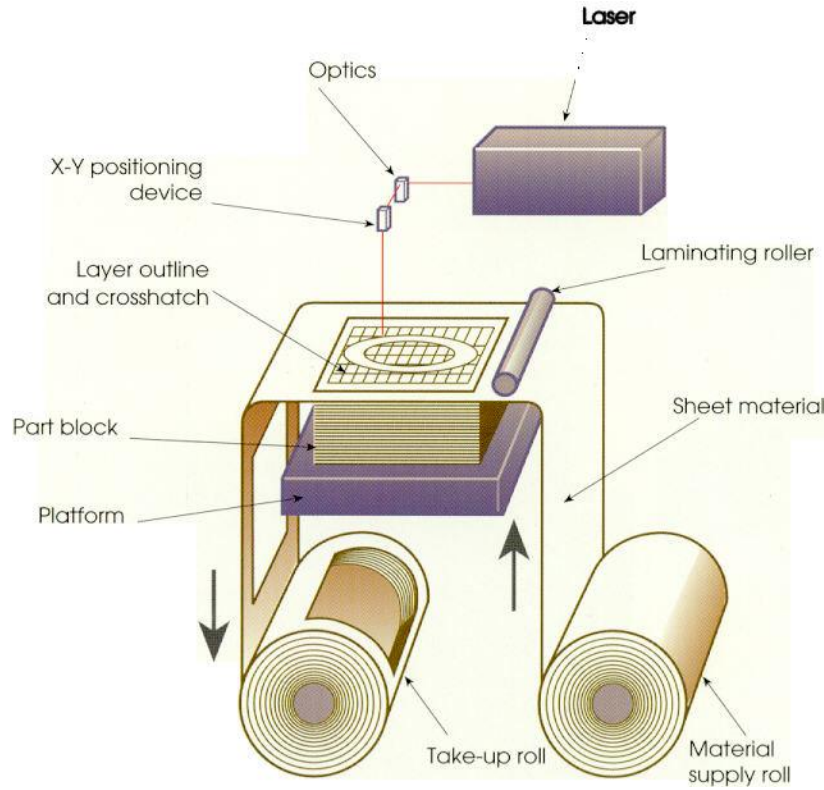
Trumpf metal laser deposition welding



https://www.youtube.com/watch?v=Ao319dj6kiM

Laminated Object Manufacture – Helisys – Cubic Technologies

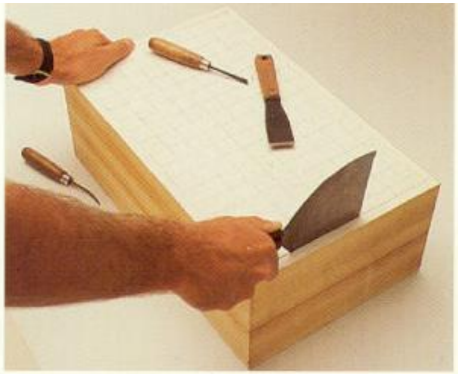




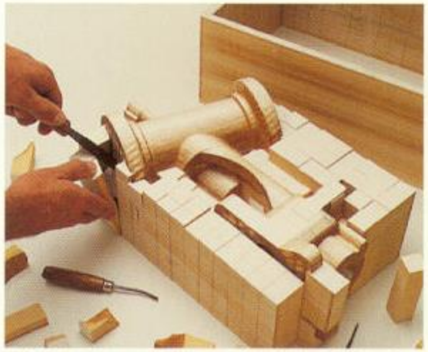
S P E C I F I C A T I O N

	LOM-2030	LOM-1015
MAXIMUM PART SIZE:	32" L x 22" W x 20" H	15" L x 10" W x 14" H
PART ACCURACY:	±0.010" X-Y-Z (relative feature location)	±0.010" X-Y-Z (relative feature location)
LASER:	50 Watt CO_2	25 Watt CO_2
LASER BEAM DIAMETER:	0.010"-0.015"	0.010"-0.015"
POSITIONING SYSTEM:	X-Y Positioning Table Moves the Laser Beam	X-Y Positioning Table Moves the Laser Beam
CUTTING SPEED:	Up to 24"/second	Up to 15"/second

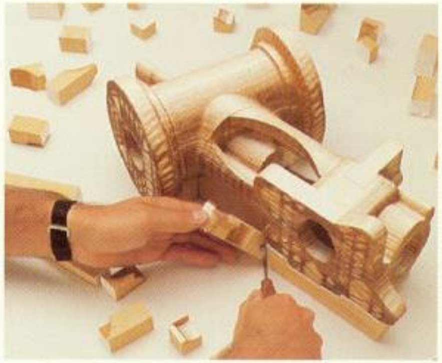
Laminated Object Manufacture



The laminated stack is removed from the machine's elevator plate.

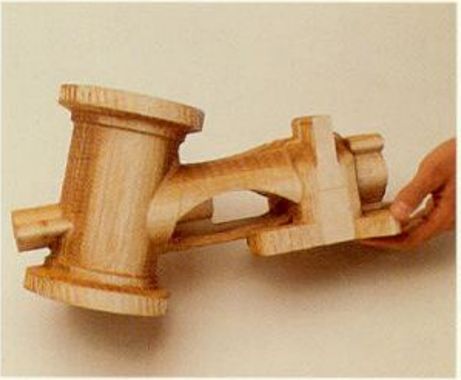


The surrounding wall is lifted off the object to expose cubes of excess material.



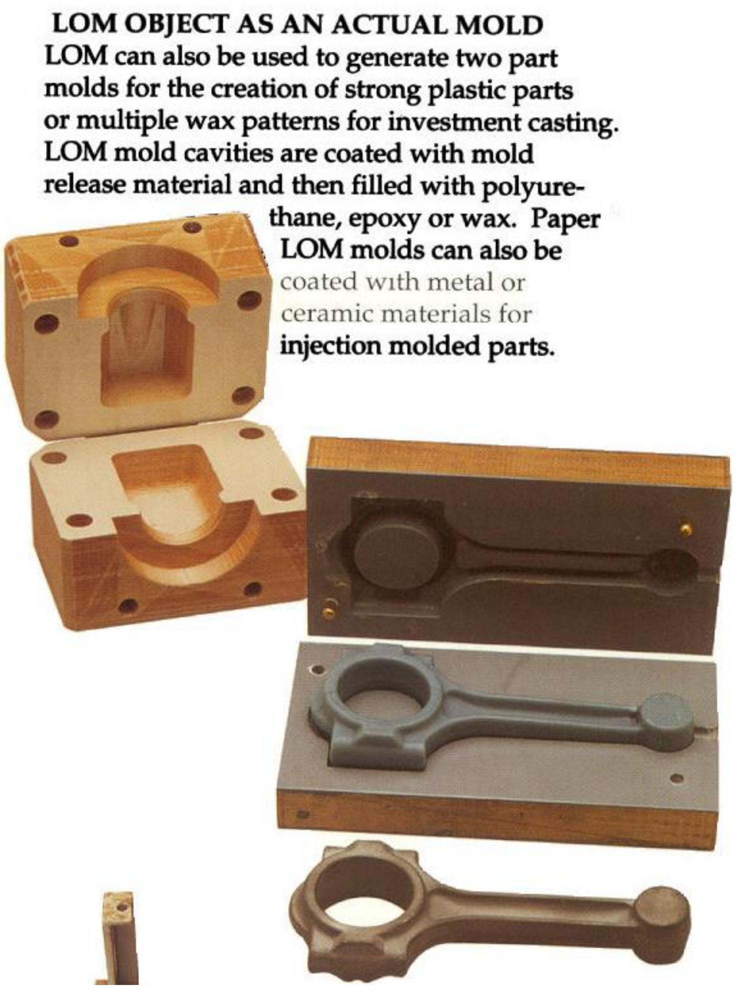
Cubes are easily separated from the object's surface.

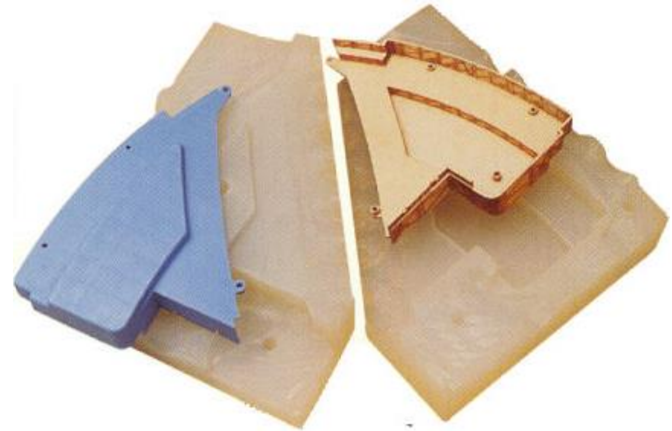
SAND CASTING
The LOM process can be used to produce solid cores or core boxes quickly by simply outlining the periphery of each cross-section. Using inexpensive LOM materials, the creation of large and bulky patterns is especially fast and cost-effective.



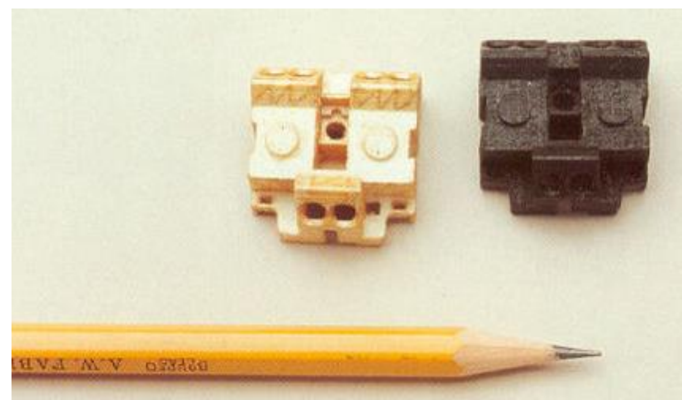
The object's surface can then be sanded, polished or painted as desired.

Laminated Object Manufacture





Silicon Rubber Moulding – Urethane or epoxy cast plastic parts



Spray Metal Moulds for prototype injection moulding

TECHNICAL SPECIFICATIONS

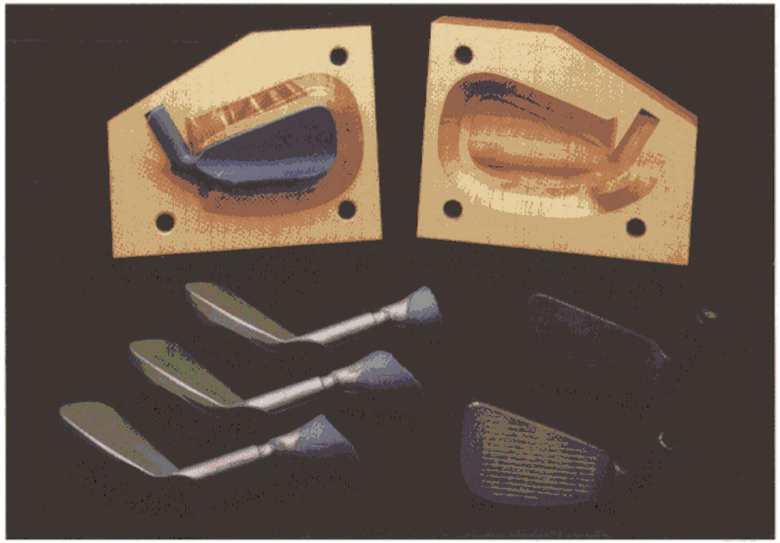
LOMPart™: Ballistic Projectiles
Company: Lufkin Industries, Inc.
Matchplate Dimensions (X-Y-Z): 17" x 12" x 3" (both plates)
Core Box Dimensions (X-Y-Z): 8" x 5" x 1.75" (both halves)
LOM System: LOM-2030
LOMPaper™: 0.0038" Double Layered
Matchplates: Data Preparation: 30 min. LOM Build : 35 hrs. Finishing: 8 hrs.
Core Boxes: Data Preparation: 30 min. LOM Build : 20 hrs. Finishing: 6 hrs.
Finishing Materials: Sanding lacquer sealer & lacquer spray

Application: **Sand Casting**
Matchplates were cast in sand and sand was injected into core box to produce over 400 prototype metal projectiles.

TECHNICAL SPECIFICATIONS

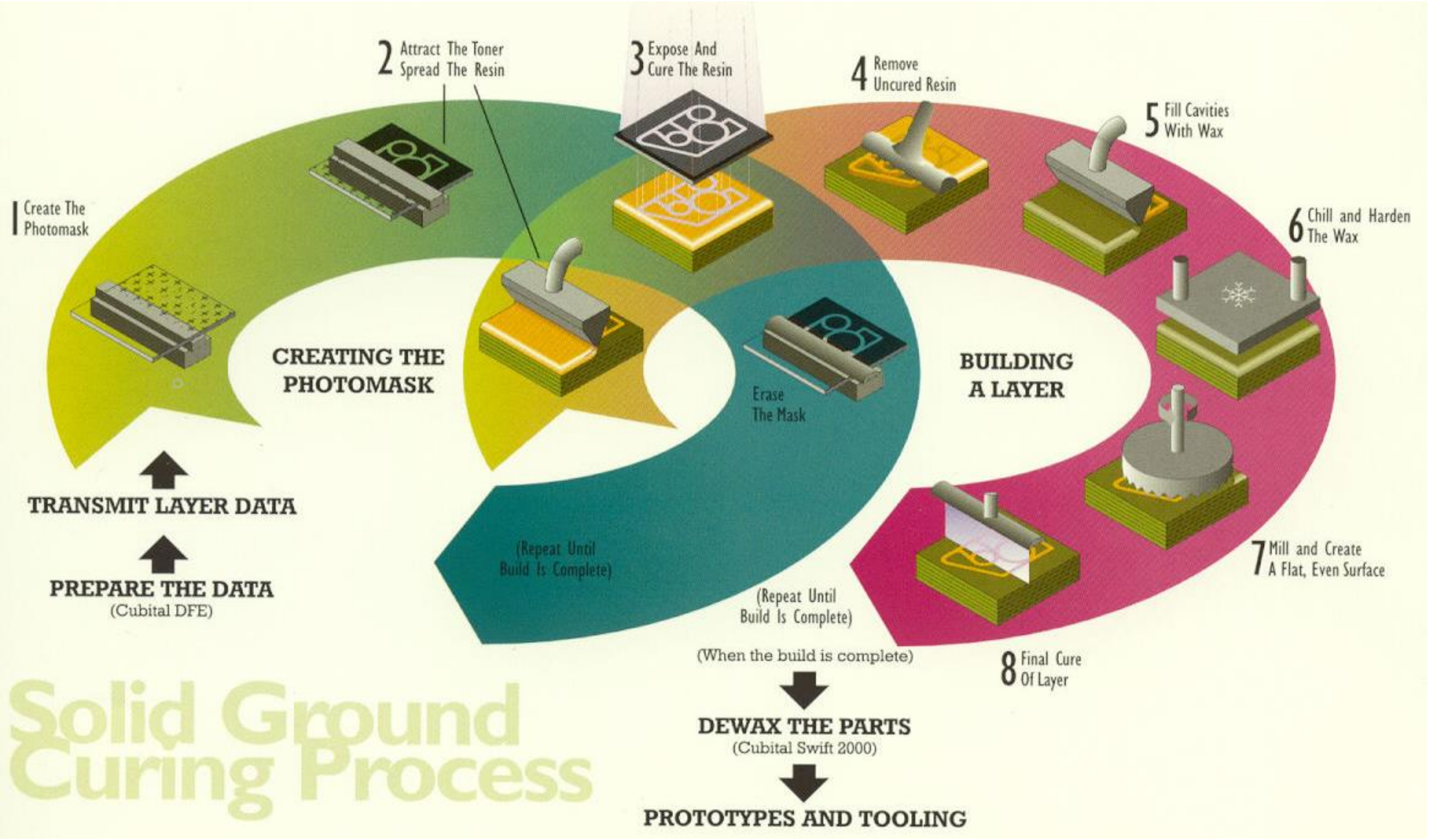
LOMPart™: Oversized 7-Iron Golf Club Head
Dimensions (X-Y-Z): 7" x 5" x 3.5"
LOM System: LOM-1015
LOMPaper™: 0.0038" Single Layer
Data Preparation: 30 min. LOM Build : 23 hrs. Finishing: 4 hrs.
Finishing Materials: Sanding lacquer sealer & lacquer spray

Application: **Investment Casting**
50 wax patterns were injected into the LOM golf club mold for the investment casting process. Resulting metal club heads were finished and tested on the golf course.

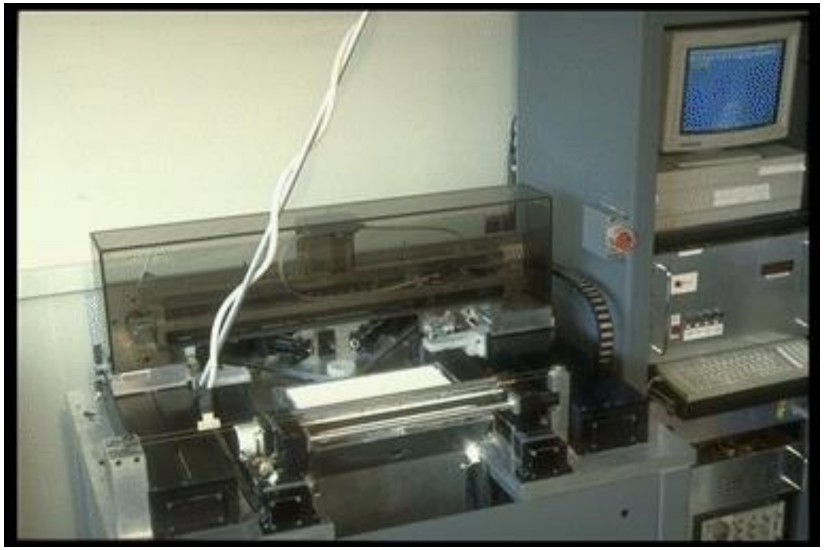


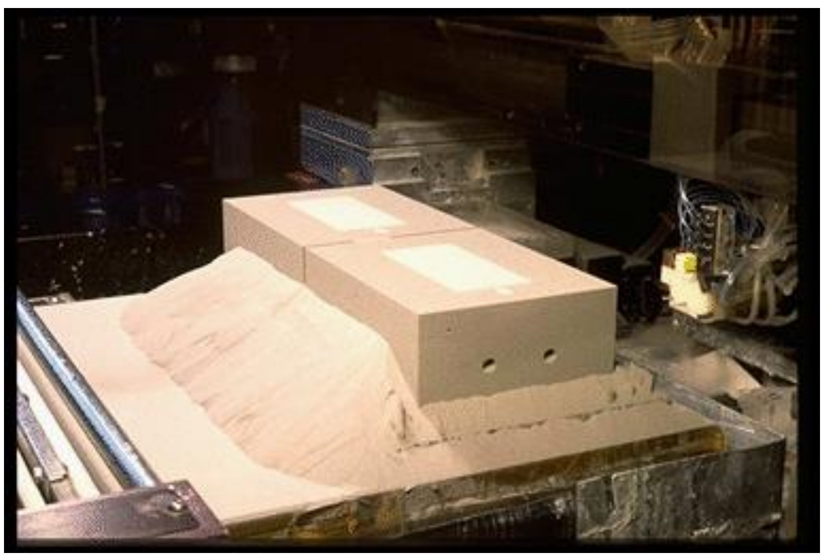
Solid Ground Curing - Cubital

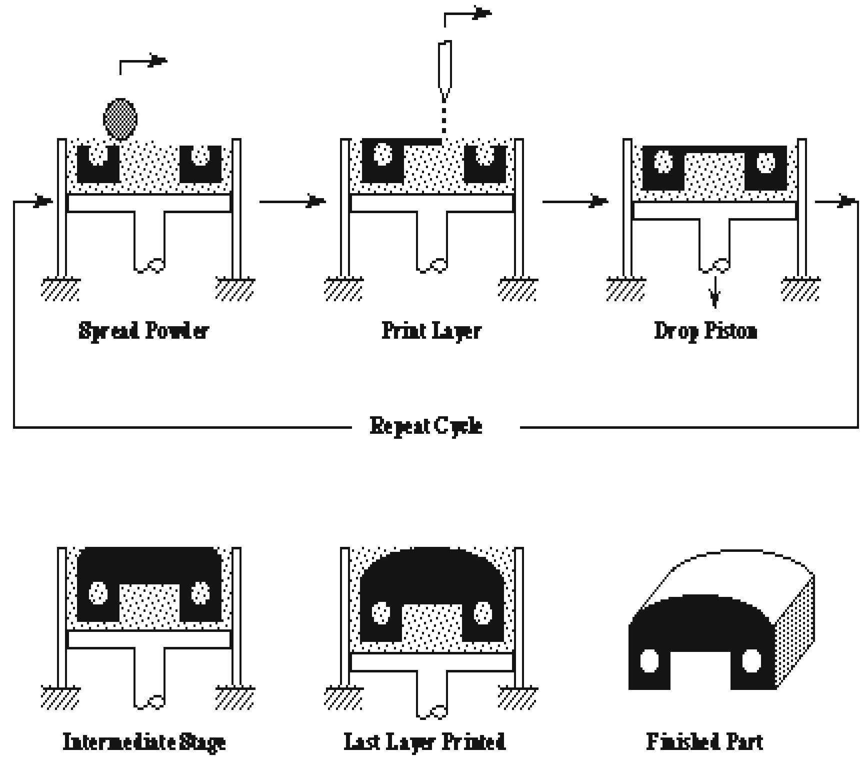
SGC 5600 – Build Envelope 500x350x500 mm – resolution 0.1 mm


1 Create The Photomask
2 Attract The Toner Spread The Resin
3 Expose And Cure The Resin
4 Remove Uncured Resin
5 Fill Cavities With Wax
6 Chill and Harden The Wax
7 Mill and Create A Flat, Even Surface
8 Final Cure Of Layer
CREATING THE PHOTOMASK
BUILDING A LAYER
Erase The Mask
(Repeat Until Build Is Complete)
(Repeat Until Build Is Complete)
TRANSMIT LAYER DATA
PREPARE THE DATA
(Cubital DFE)
(When the build is complete)
DEWAX THE PARTS
(Cubital Swift 2000)
PROTOTYPES AND TOOLING
Solid Ground Curing Process

MIT Alpha Machine – 3D Printing

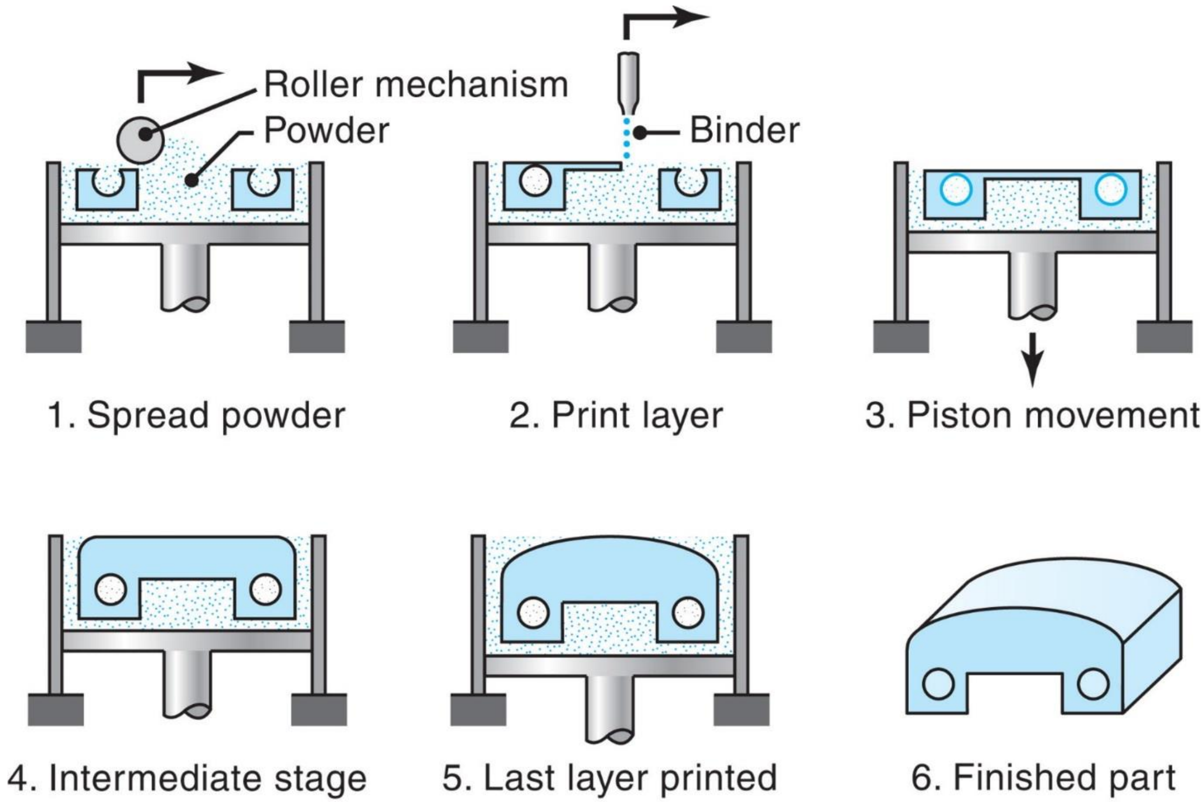






Schematic illustration of the three-dimensional-printing process.

Source: After E. Sachs and M. Cima.

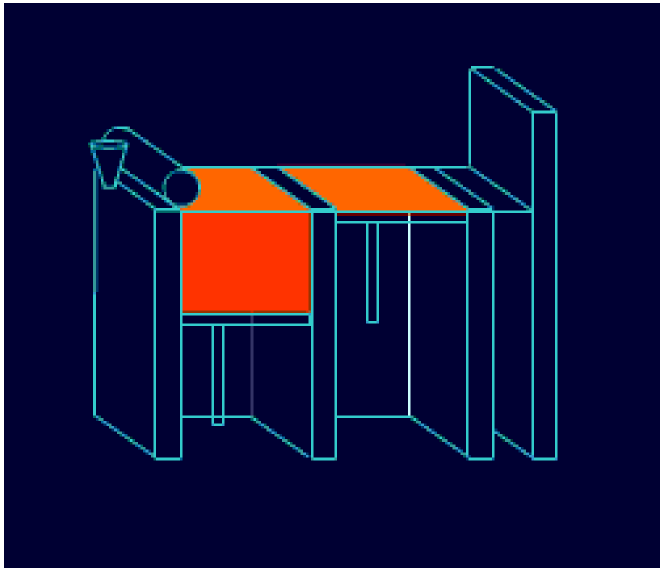


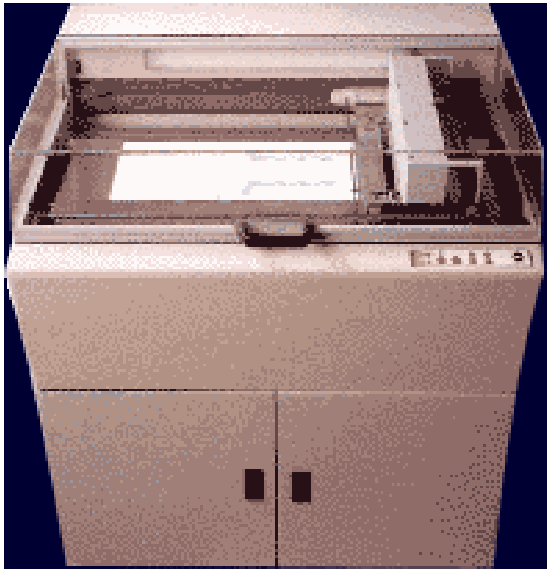
https://www.youtube.com/watch?v=7QP73uTJApw

Materials for Z Corporation's Machines now 3D systems

	zp14 powder	zp100 powder
Composition	starch/cellulose	plaster
Layer Thickness	0.004- 0.01 inches	0.003 - 0.004 inches
Part Strength	4 MPa	10MPa
Speed (approx. depending on part size)	1 vertical inch per hour	0.5 vertical inches per hour
Ability to Reuse Unprinted Powder	yes	yes

Principle of Operation





The machine spreads a layer of powder from the feed box to cover the surface of the build piston.

The Z402 System then prints binder solution onto the loose powder, forming the first cross-section.

Where the binder is printed, the powder is glued together.

The remaining powder remains loose and supports the layers that will be printed above.

When the cross-section is complete, the build piston is lowered slightly, a new layer of powder is spread over its surface, and the process is repeated.

The part grows layer by layer in the build piston until the part is complete, completely surrounded and covered by loose powder.

Finally the build piston is raised and the loose powder is vacuumed away, revealing the complete part.

Z™402 3D PRINTER
Build Volume: 8" x 10" x 8"
(203 x 254 x 203 mm)

Z Corporation 3D Colour Printing

Z™402C 3D COLOR PRINTER

Build Speed: Colour Mode: 0.33-0.66 vertical inches (8-16 millimeters) per hour at 0.007" layer

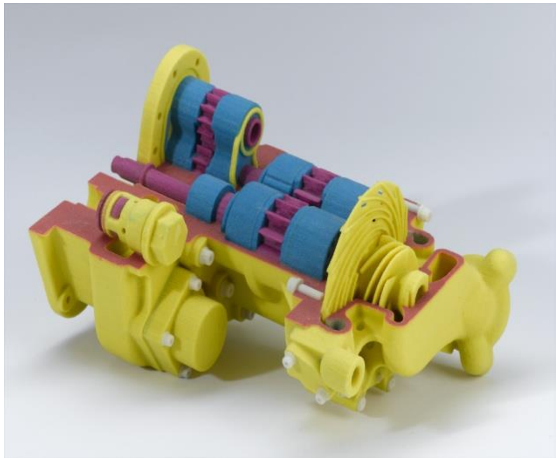
Build Volume: 6" x 6" x 6" (150 x 150 x 150 mm)

Layer Thickness: User selectable at the time of printing. 0.003"-0.010"(.076-.254 mm)

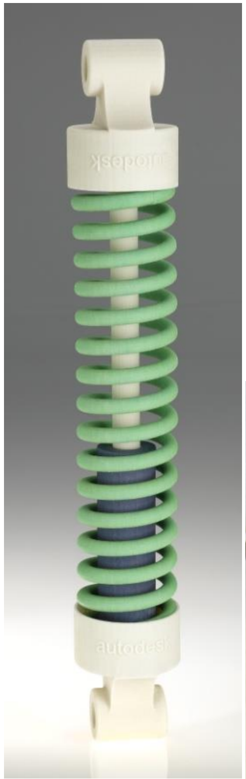
Materials: The Z402C System requires zb™7 binder. While both starch-based powder and plaster-based powder may be used, the plaster-based powder produces colours that are more brilliant. Colour is applied to the surface of the parts to a uniform depth of approximately 0.08 inches or 2 mm.

Equipment Dimensions: 29" x 39" x 42" (74 x 99 x 107 cm)

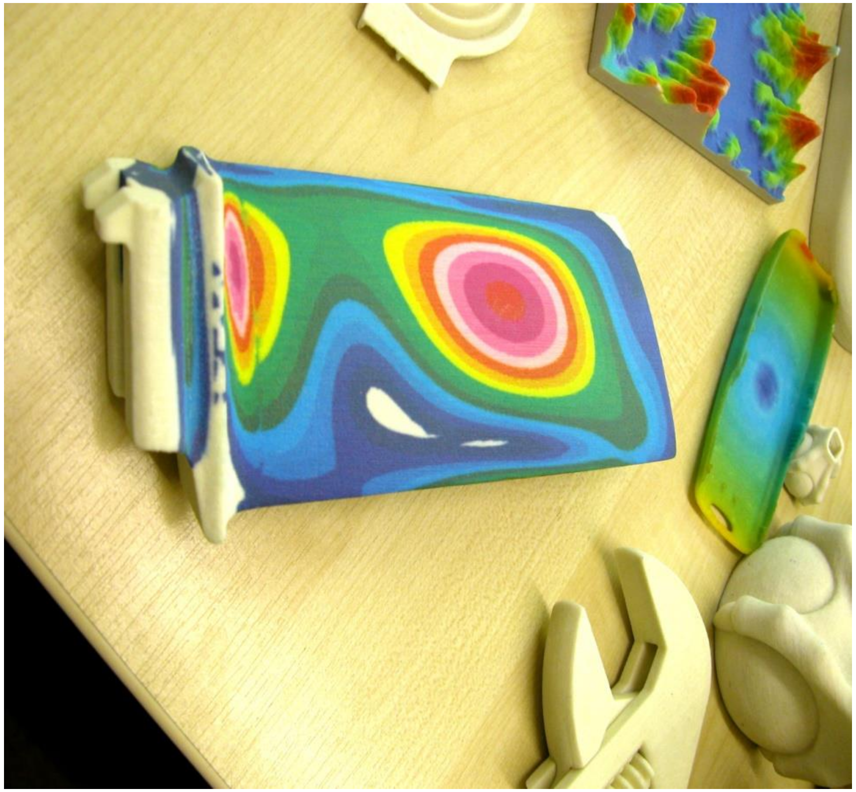
Sussex Machine

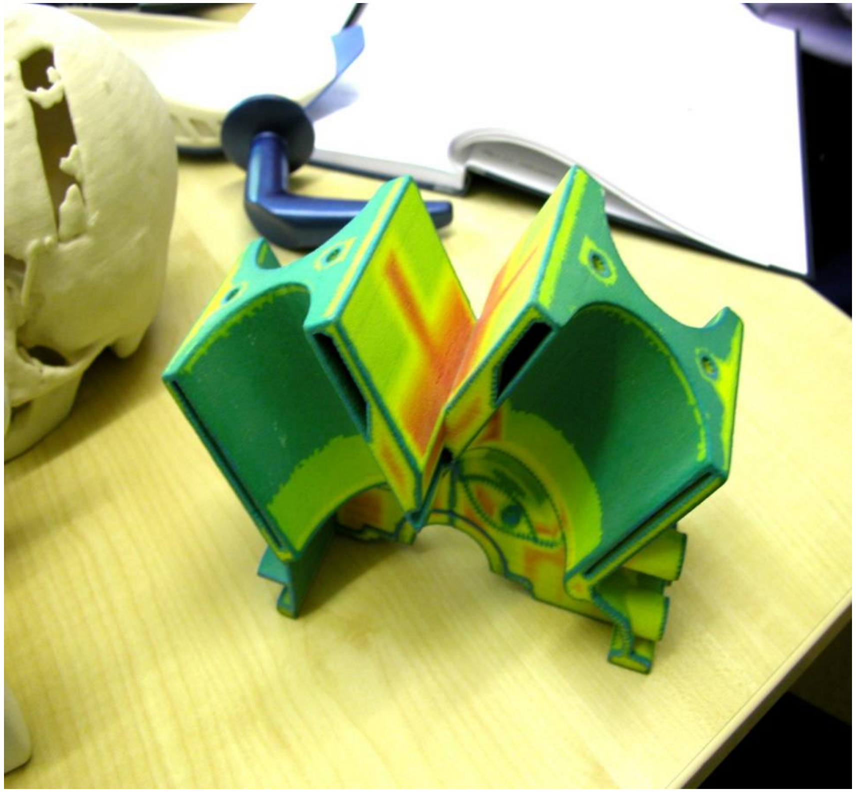


Parts Created



Flow & Thermal Analysis





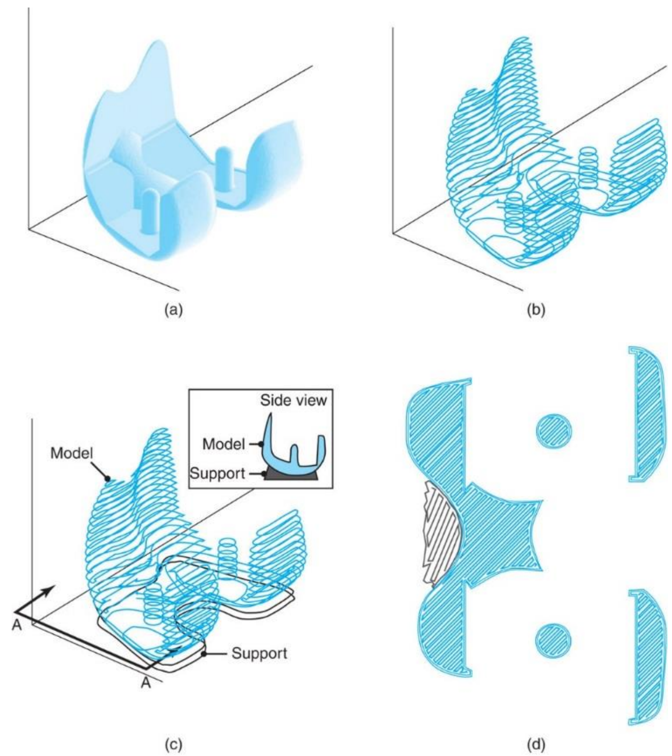
The computational steps in producing a stereolithography (STL) file

(a) CAD Three-dimensional description of part.

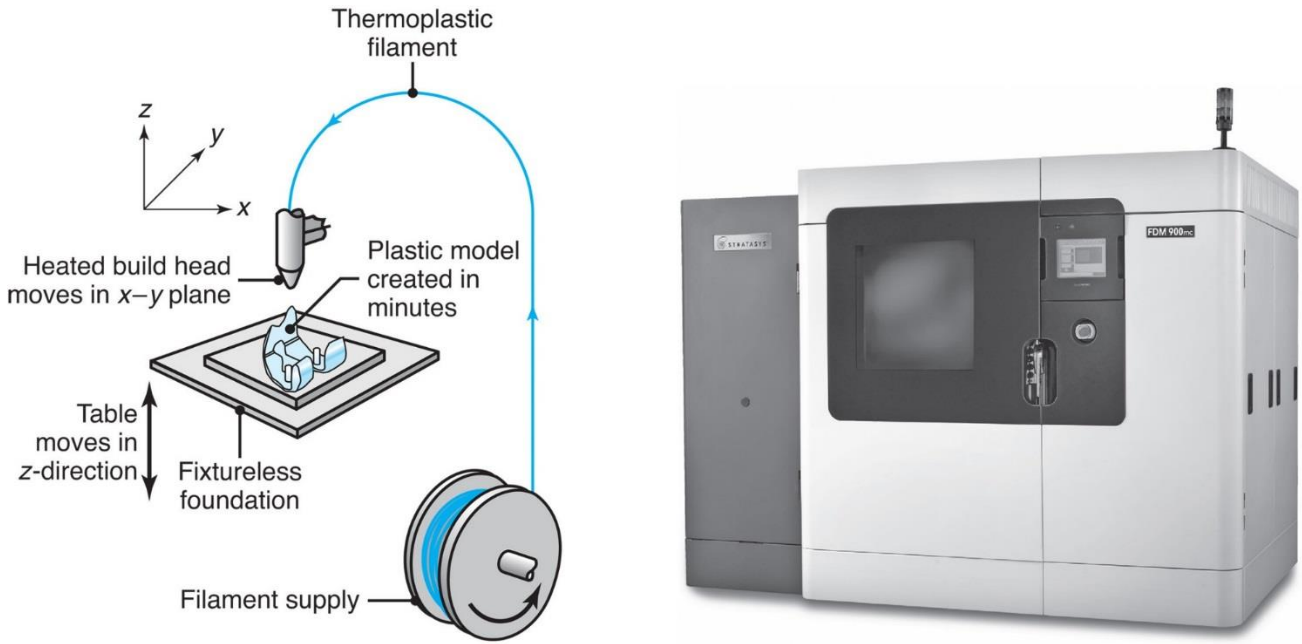
(b) The part is divided into slices: only 1 in 10 is shown.

(c) Support material is planned.

(d) A set of tool directions is determined to manufacture each slice. Also shown is the extruder path at section A–A from (c) for a fused-deposition modeling operation.



(a) Schematic illustration of the fused-deposition modeling process. (b) The FDM 900mc, a fused-deposition-modeling machine. *Source:* Courtesy of Stratasys, Inc.

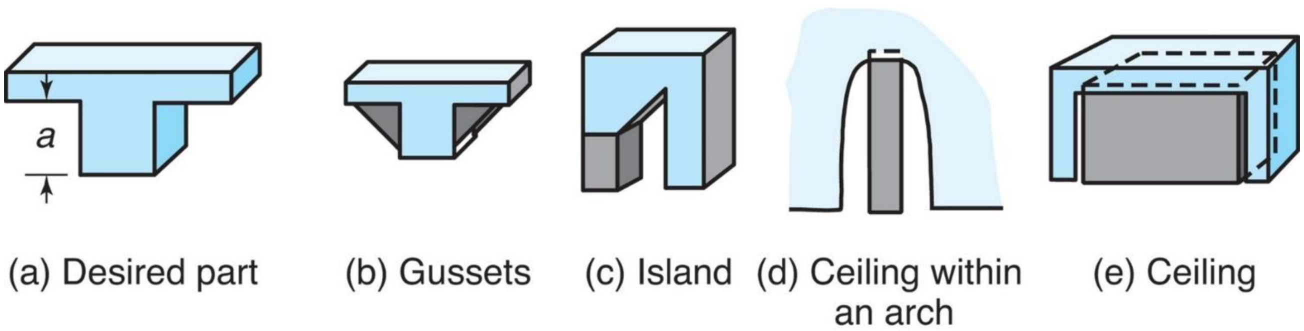


(a) (b)

(a) A part with a protruding section that requires support material. (b) through (e) Common support structures used in rapid-prototyping machines. The gray areas are support material.

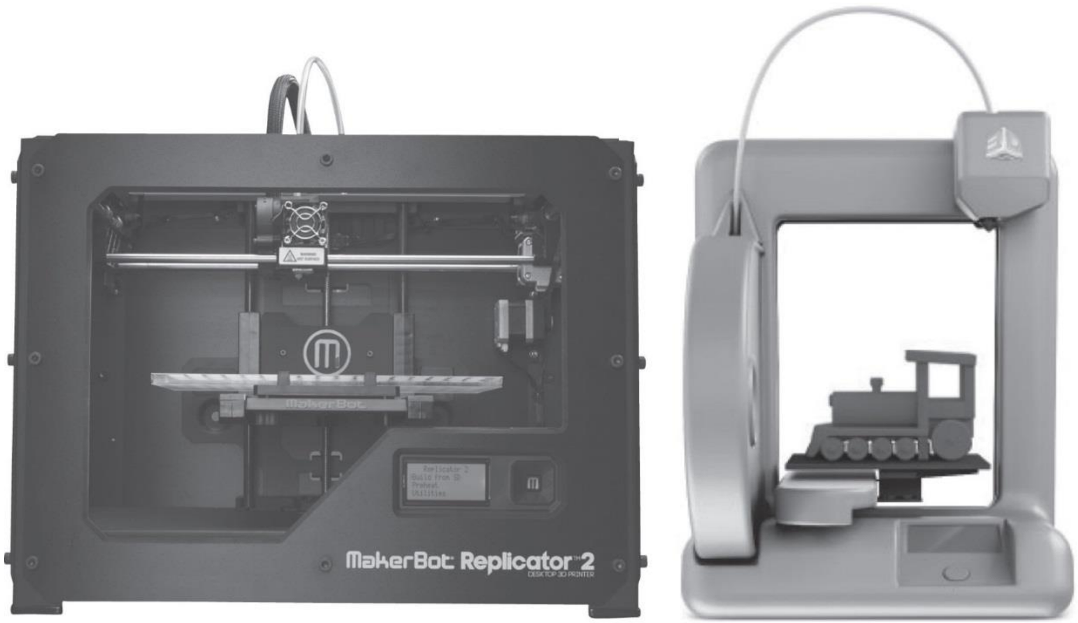
Source: Reused with permission from Society of Manufacturing Engineers.

https://www.youtube.com/watch?v=ik39_sv-wgQ FDM



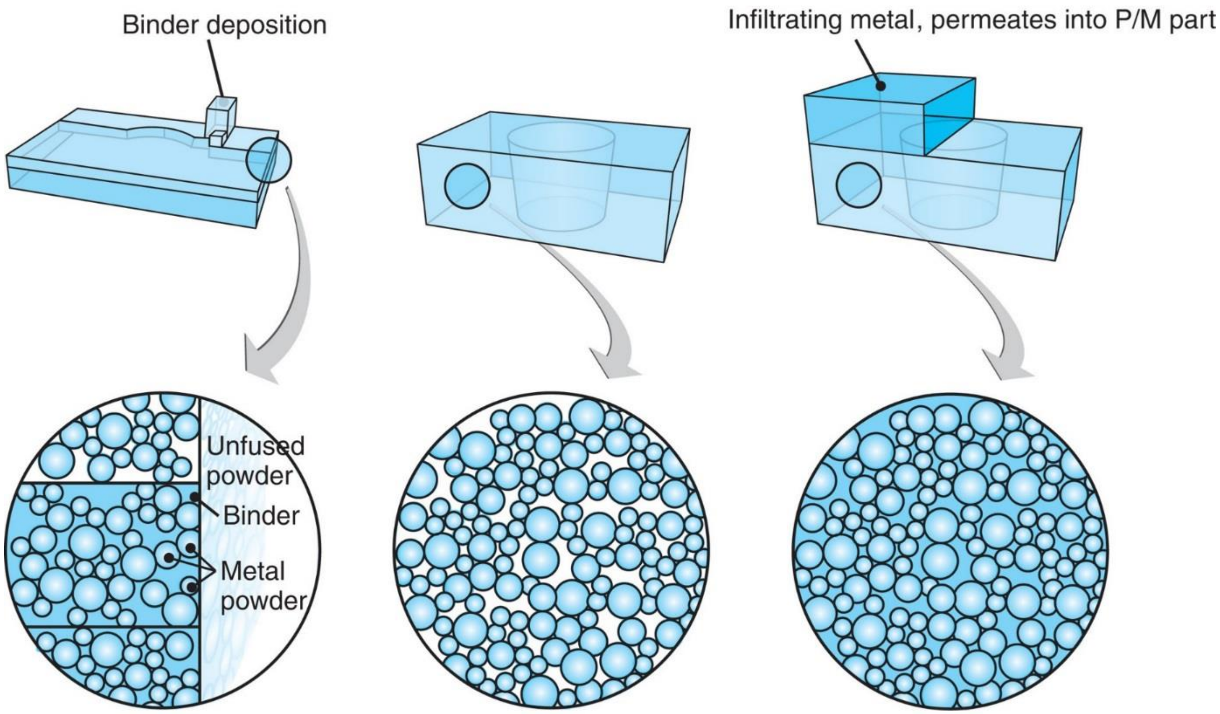
Examples of low-cost rapid-prototyping systems, based on fused-deposition modeling. (a) The MakerBot® Replicator® 2 Desktop 3D printer, based on fused-deposition modeling and open-source software, with a build volume of up to 110 mm × 110 mm × 120 mm, using either ABS or PLA (polylactic acid) polymers and (b) the Cube, with a build space of up to 140mm × 140 mm × 140 mm.

Source: (a) Courtesy of MakerBot, Inc. (b) Courtesy of 3D systems.



(a) (b)

Three-dimensional printing using (a) part-build; (b) sinter; and (c) infiltration steps to produce metal parts. *Source:* Courtesy of The ExOne Company.



(a) Microstructure detail

(b) Particles are loosely sintered
Binder is burned off

(c) Infiltrated by
lower-melting-point metal

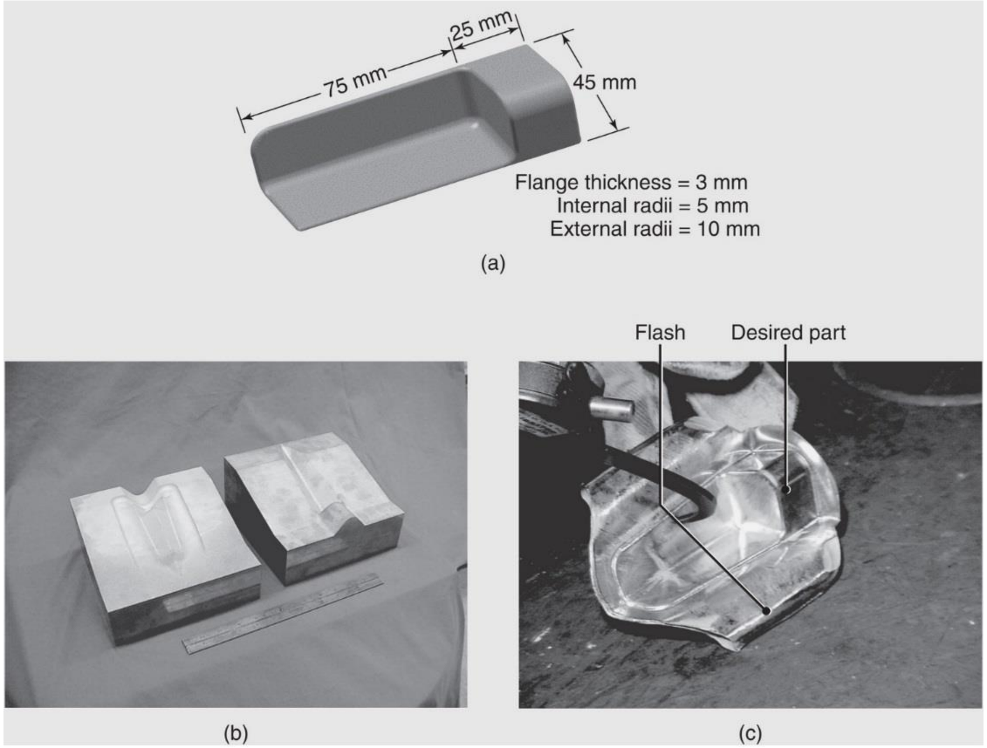
https://www.youtube.com/watch?v=i6Px6RSL9Ac

Rapid-prototyped versions of user-defined characters, or avatars, produced from geometric descriptions within popular websites or games. (a) Second Life avatar, as appears on a computer screen (left) and after printing (right) and (b) an avatar known as "Wreker" from World of Warcraft.

Source: (a) Courtesy of Z Corporation. (b) Courtesy of Figure Prints and Fabjectory, Inc.

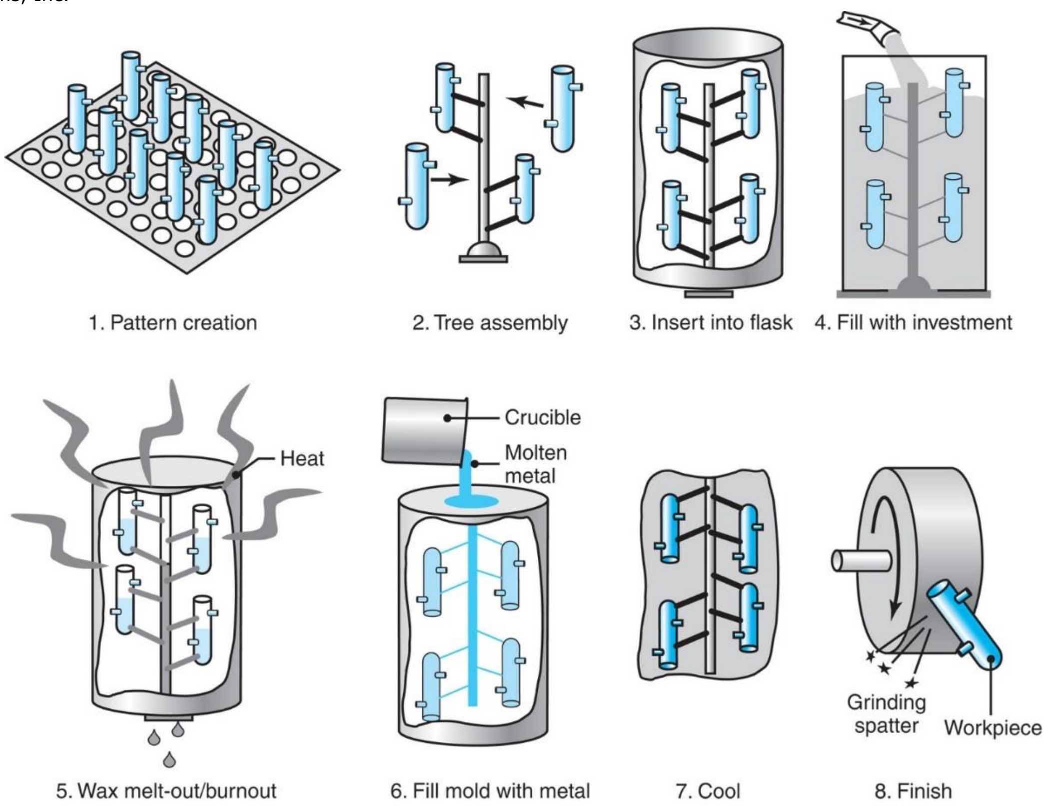
A fitting for a helicopter fuselage. (a)CAD representation with added dimensions. (b) Dies produced by three-dimensional printing. (c) Final forged workpiece.

Source: (a) Courtesy of The ExOne Company; (b) and (c) Courtesy of Kennametal Extrude Hone Corporation.

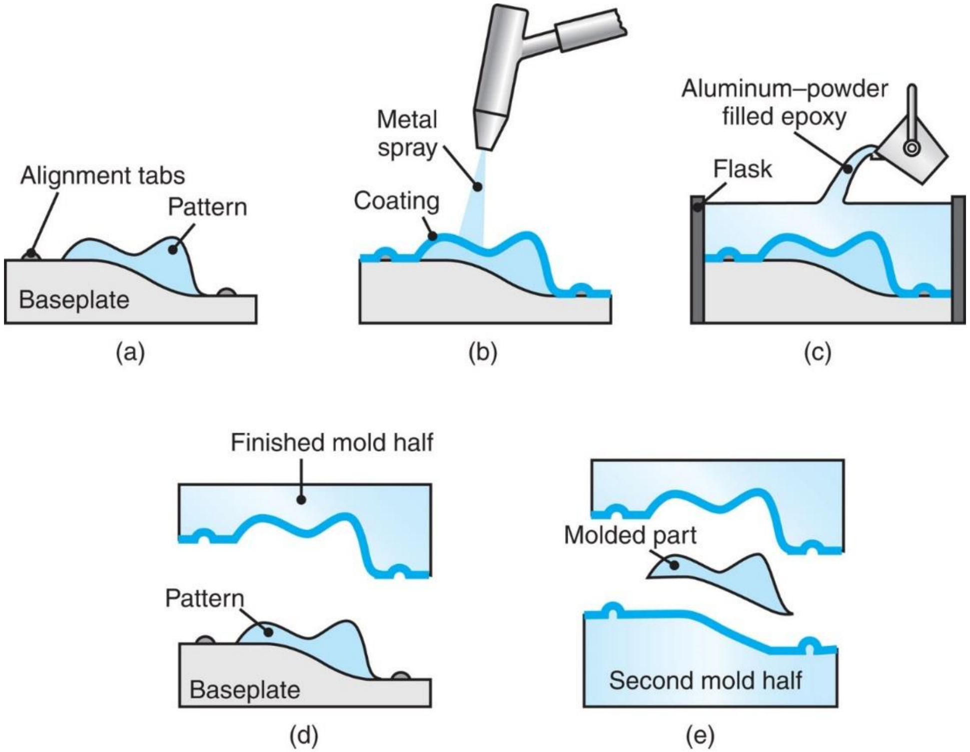


Manufacturing steps for investment casting with rapid-prototyped wax parts as blanks; this method uses a flask for the investment, but a shell method also can be used.

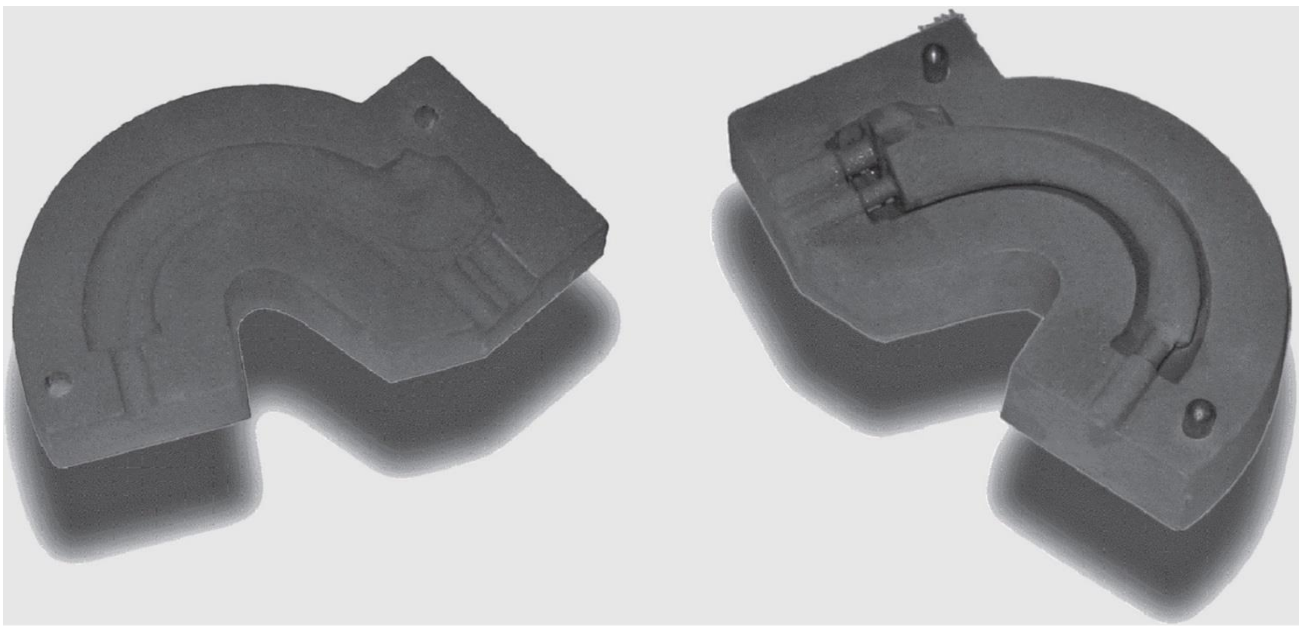
Source: Courtesy of 3D Systems, Inc.



Production of tooling for injection molding by the sprayed-metal tooling process.
(a) A pattern and baseplate are prepared through a rapid-prototyping operation;
(b) a zinc–aluminum alloy is sprayed onto the pattern;
(c) the coated baseplate and pattern assembly are placed together in a flask and backfilled with aluminum-impregnated epoxy;
(d) after curing, the baseplate is removed from the finished mold; and
(e) a second mold half suitable for injection molding is prepared.

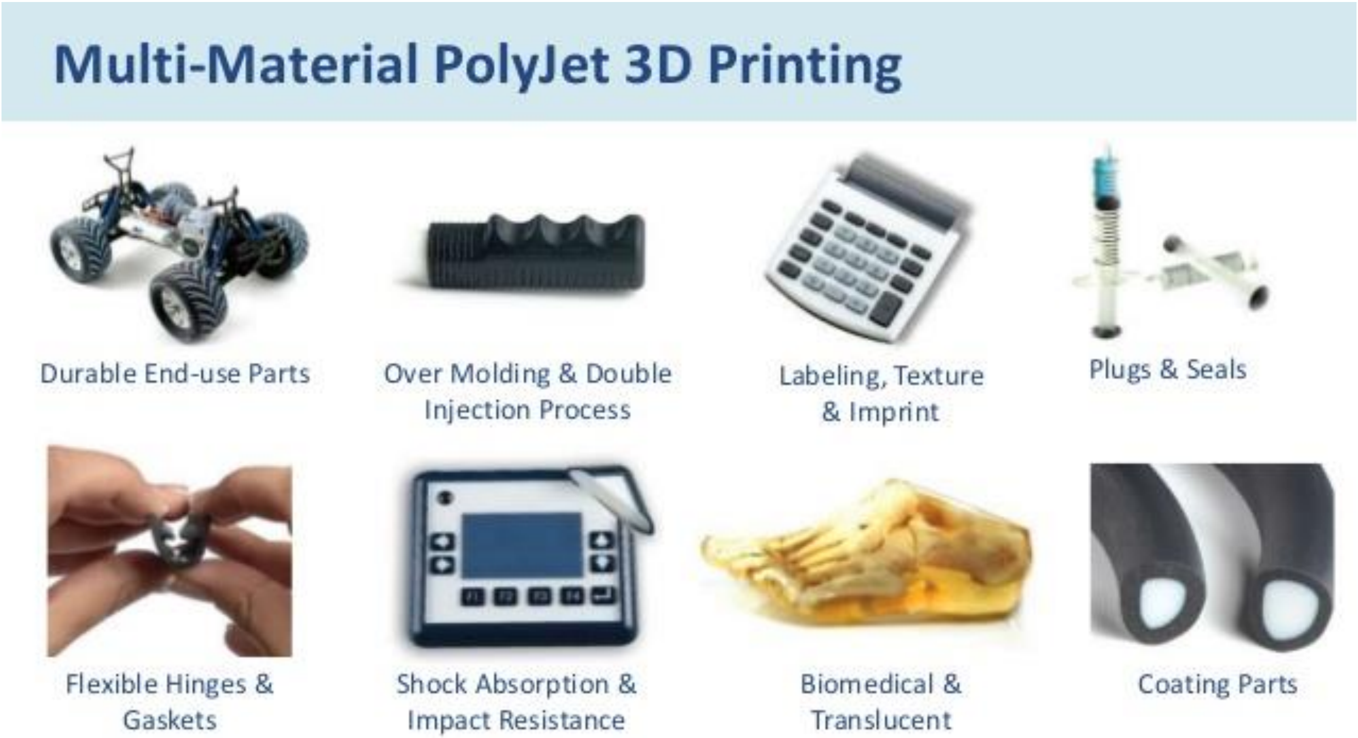


Sand molds produced through three-dimensional printing.



New faucet design, produced by casting from rapid prototyped sand moulds.

Multi Material PolyJet 3D Printing



https://www.youtube.com/watch?v=D4Yq3glEyec

Hp Polymer jet

http://www.youtube.com/watch?v=MrQr_gdI-ss&feature=endscreen&NR=1

REP RAP

http://www.youtube.com/watch?v=FUB1WgiAFHg

https://www.youtube.com/watch?v=rjYA1w1uuAw

https://www.youtube.com/watch?v=s9IdZ2pI5dA **additive subtractive manufacture**

Hair Dryer